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WATER MOTORS.

A Lecture by PROFESSOR W. C. UNWIN, B. Sc., M. Inst. C. E.

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WHEN the Council did me the honor to ask me to lecture on Hydraulic Motors, I I could not but feel that they imposed on me a task of some difficulty. The lectures of last year on the applications of steam-power related to a matter of pre-eminent national importance, and to one involving some of the most striking and brilliant scientific discoveries of this century. In describing the work of Joule and Rankine and Siemens, the lecturers of last year were recalling names familiar and honored in this Institution, and discoveries which form the most characteristic scientific advance of recent times.

Water motors are not now, or in this country, so important as heat motors, and there is even possibly, among many engineers, an impression that water motors are at best rather feeble machines, suitable only for small industries. Nevertheless, I believe that even now a much larger amount of water-power is utilized than is generally known, and in circumstances not impossible, or even very improbable, the importance of water-power even in this country, might be greatly increased. In some by no means very indefinitely deferred period, there must begin to be felt something of the pressure due to the limitation of the coal supply. No great increase of the price of coal is needed to make water-power much more valuable than it is at present. On the other hand, if the electrical engineer will make the transmission of energy easier, the importance of water-power would also increase, for one of its greatest defects is that it exists in the localities where nature has placed it, and not in the places where it can be most conveniently used.

Numerous isolated cases of the transmission of energy electrically, to do mechanical work at a distance, are no doubt already in successful operation, but in most of these cases the installation has been more or less of an experiment, and the cost has not been greatly regarded. But one case, in which the electrical transmission of water-power has been successfully carried out on a strictly commercial basis, has come under my notice. At Bienne, in Switzerland, the power of a Girard turbine is transmitted electrically a distance of 4,000 feet, and used to drive workshops. The dynamos are compound-wound, and the conductors are carried on posts. A diminution in the cost of electrical apparatus would probably render such cases much more numerous.

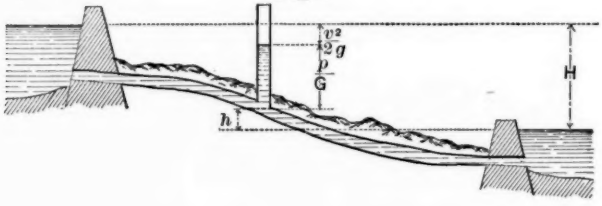
The term water-power is convenient, but inaccurate. Strictly speaking, there is no such thing as water-power. Whether the water descends on a water wheel, or actuates a pressure-engine in connection with Mr. Ellington's hydraulic pressure-mains, the water is a mere agent of transmission. In one case the water wheel is driven by the energy of gravitation, in the other by the energy developed in a

steam-engine; the water merely transmits the pull of gravity or the push of the steam-engine. In neither case is the water itself the source of the power utilized. As we speak of a steam-engine as a heat motor, so we might speak of most water motors as gravity motors.

However, using the term water-power as a convenient one, it may be pointed out that, though a good deal of water-power is already utilized in this country, and though a few motors of very considerable power exist here, it is on the Continent and in America, where coal is dearer, that the most striking instances of the utilization of water-power are to be found. Many members of this Institution have probably seen the turbines at the falls of Schaffhausen, the power of which is distributed to several mills by wire ropes. In the report of the Technical Education Commission there is an interesting account of a visit to Windisch, where 1,000 H.P. are utilized, the weir and turbines having cost £70,000. At Bellegarde, at the confluence of the Rhone and the Valserine, on a fall of 40 feet, 3,700 H.P. are utilized by six turbines, and this amount of power would have been doubled if the project had been commercially successful. Water-power is utilized on a still larger scale in America.

Holyoke and its Water-power.—About 18 miles from the mouth of the Connecticut river there was a fall of about 60 feet in a short distance, forming what were called the Great Rapids, below which the river turned sharply, forming a kind of peninsula, on which the city of Holyoke is now built. In 1831 the first mill was erected and driven by water-power. In 1845, the magnitude of the water-power available attracted attention, and it was decided to build a dam across the river. The ordinary flow of the river is 6,000 cubic feet per second, giving a gross power of thirty thousand horses, or in dry seasons probably not less than twenty thousand horses. In a recent exceptional summer it seems to have fallen, for a time, to half this amount. The first weir or dam was completed in in 1847, but it was carried away. A second dam was built in 1849, with a base of 80 feet and a height of 30 feet. The dam is a timber cribwork filled with stone, and rests on rock. In 1868 it was found necessary to construct an apron to this weir, 50 feet in width. The whole structure is now 130 feet wide, 30 feet above the river bed, and 1,019 feet in length. From above the weir, a system of canals takes the water to the mills on three levels. The first canal starts with a width of 140 feet, and depth of 22 feet. A second canal, parallel through a distance of a mile with the first, takes the water after passing through the mills, and supplies it to a second series of mills. There is also a third canal, at a different level.

Fig. 1



With the grant of land for a mill is also leased the right to use the water-power, and the lease of the water-power is transferred to successive tenants with the lease of the mill. A mill-power is defined as 38 cubic feet of water per second, during 16 hours per day, on a fall of 20 feet. This gives a gross power of eighty-six horses, or an effective power, with a good turbine, of about sixty-three horses. The charge for the power is at the rate of 20s. per horse-power per annum. Mr. Emerson, from whom I borrow my data, may well say that Holyoke affords the cheapest manufacturing power in the world.

There are numerous other cases in America where water-power is supplied

in a similar way at a cost varying from £1 to £5 per horse-power per annum. At Bellegarde, I believe, the proposed charge was £8 to £12 per horse-power per annum.

The ordinary source of water-power is a supply of water raised by the sun's heat to a convenient elevation, and falling through natural channels back to the sea. On each pound of water descending H feet, gravity does H foot-pounds of work. We call H the head due to the elevation, meaning by head the energy per pound of water which would be communicated by gravity during its descent, and which is recoverable by suitable machinery.

Suppose the water to descend at a uniform rate through a pipe (Fig. 1), whcih we may imagine frictionless. At any point h feet above the lower level, the water will in general have acquired a pressure p and a velocity v. And in that case we know that

$$H = h + \frac{p}{G} + \frac{v^2}{2g}$$

where h is the unexpended part of the fall, $\frac{p}{G}$ is the energy corresponding to the pressure, and $\frac{v^2}{2g}$ the energy corresponding to the velocity of each pound of water. Consequently, the head may take three different forms, and, at whatever point of the pipe we make the examination, these three portions of head add up to the same total amount.

Corresponding to each of these three forms which the head takes, there is a class of water motors. By a bucket water-wheel we can recover the energy corresponding to an unexpended part of the fall; by a pressure-engine we can get the energy due to the pressure, and by a turbine we can get the energy due to the velocity.

I.—Bucket or Cell Wheels.

First, then, there are bucket or cell wheels, in which the water fills the buckets near the top of the fall and descends in contact with the wheel without acceleration.

About this class of motors I have time to say very little. They are simple in principle, and have a fairly high efficiency. But they are somewhat cumbrous and antiquated machines. On falls above 70 feet they cannot be used. On falls of 20 to 60 feet a turbine is cheaper, and yields an equal efficiency. On a low fall, if a turbine costs as much, it has, if well constructed, a higher efficiency. Still in one respect a good overshot or high-breast wheel is superior to most more modern water motors. Its efficiency is nearly the same with a reduced supply of water as with the full supply. In this respect many turbines, otherwise excellent, compare very unfavorably with the water wheel. It is probably because many turbines are not so good as they might be, and because many are extremely bad, that the water-wheel is still constructed for the falls for which it is most suitable.

II. Pressure Engines.

The second way of utilizing water-power is to bring the water to the level of discharge in a closed pipe at small velocity, but with a pressure but little less than that due to the height of fall. The water under pressure acts on the piston of a pressure-engine precisely as steam acts in a steam-engine. There are numerous hilly mining districts, especially in Germany, where water-pressure engines are used. Hydraulic lifts and hydraulic cranes in connection with accumulators, are pressure-engines driven by an artificially-created head of water.

Now, although a water-pressure engine is, in certain cases, a perfectly successful and economical machine, it is not, in most cases, the best plan to utilize water power in this way. It may, perhaps, be instructive to consider why, almost without exception, we use a cylinder and piston with steam, and yet only exceptionally resort to the same expedient with water.

The great difference between steam under pressure and water under pressure is this—that one is a comparatively light fluid indefinitely expansible, the other a comparatively heavy fluid, the volume of which is not measurably changed by any ordinary variation of pressure.

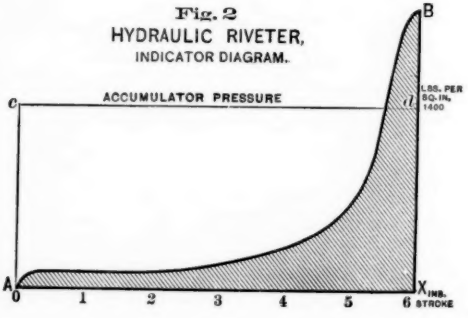
The frictional losses of energy in a fluid are proportional to its weight. If, for instance, water is 500 times heavier than steam, then at the same velocities of flow the frictional losses are 500 times greater in the water than in the steam.

To prevent enormous waste of energy in friction, a water-pressure engine must be run much more slowly than a steam-engine, and all the pipes and passages for a given volume of flow must be much larger. A steam-engine has a piston speed of 400 or 500 feet per minute; a water-pressure engine rarely has a speed exceeding 80 feet per minute. Steam flows in steam-pipes with a velocity of 100 feet per second, but in the passages of a pressure-engine the velocity of the water does not exceed 4 to 6 feet per second. Hence, for a given power a water-pressure engine is much more cumbrous than a steam-engine, except in those cases were the water-pressure is 8 or 10 times as great as is practicable with steam. It is just when an exceptionally high pressure can be obtained, or requires to be used, that the water-pressure engine is most applicable.

The second difficulty in the use of water in a pressure-engine arises out of its incompressibility. The same volume of water, and, consequently, in most cases, the same amount of energy must be expended each stroke, whether the resistance is great or small. If a hydraulic lift rises, the same volume of water is expended whether the lift is empty or loaded. Where the work is intermittent, this disadvantage is often far more than counterbalanced by the other advantages of the use of water. But where the work is continuous, the waste of energy is more serious. Suppose a pressure-engine is employed—as it not uncommonly is—in pumping. Then the pressure cylinder must be so proportioned that the work is done when the fall supplying the pressure is lowest and the lift highest. If the fall increases or the lift diminishes, no economy of water is realizable, but some prejudicial resistance by throttling must be created to prevent the engine running away and to absorb and waste the surplus energy. Such engines only work, with good efficiency, with a constant fall and lift, and only then when quite exactly proportioned to the work to be done.

Many years ago Sir W. Armstrong invented the plan of distributing hydraulic power in towns. For doing intermittent work, especially for lifting purposes, the system of hydraulic-pressure mains has proved altogether successful; the most remarkable application being the system of several miles of mains worked at a pressure of 800 pounds per square inch, and successfully laid in the streets of London by Mr. Ellington. Hitherto, however, the system has not proved so useful for ordinary power purposes, as was no doubt originally expected. The pressure is too great to be conveniently applied in a turbine, and the pressure-engine in its ordinary form is too extravagant in its consumption of water for ordinary power purposes.

Fig. 2
HYDRAULIC RIVETER,
INDICATOR DIAGRAM.



It has been proposed to admit a variable quantity of water to the pressure cylinder from the pressure main, and to complete the stroke with water drawn from a low-level reservoir. The driving effort would then be very irregular, but the plan does not seem impossible. Some years ago Mr. Hastie invented a pressure-engine, in which, by very ingenious automatic gear, the stroke of the engine is varied, diminishing when the

resistance decreases, and increasing when the resistance increases.

Through the kindness of Mr. Ellington, a drawing is exhibited of an improved "Hastie" engine, which is being introduced for power purposes in London. The engine has fixed cylinders, on the plan of the "Brotherhood" engine, and the spring gear which alters the stroke is much simpler than in the original engine.

There are other peculiarities in the action of water-pressure engines, which arise out of the weight and incompressibility of the acting fluid. In the first place, the whole column of water between the pressure cylinder and the supply reservoir virtually forms part of the piston of the engine, so that a water-pressure engine is, in general, an engine with a very heavy piston. The effect of the inertia of the piston is very well understood. It tends to make the effective effort transmitted smaller than the pressure on the piston in the first half of the stroke, and greater than the pressure on the piston in the second half of the stroke. In a steam-engine this is often an advantage. The diminution of steam-pressure, due to expansion, can be in great part neutralized by the effect of the inertia of the piston. At any rate, the inertia of the piston generally tends to diminish the inequality of the driving effort. It is otherwise with a water-pressure engine, in which the water-pressure, being constant, the effect of inertia is to render the driving effort variable; and this is so much the less advantageous, because, while with the light fluid, steam, we can neglect the weight of the fluid, with water we must reckon the weight of water in the supply pipe as forming part of the piston.

I believe that the precise part played by the inertia of the water in the motion of a pressure engine has first been indicated by Professor Cotterill in his "Treatise on Applied Mechanics." He has specially treated of the case of a rotating engine, while I shall consider rather those pressure-engines which make a stroke, uncontrolled by a crank and fly-wheel. In such engines the inertia of the fluid behind the piston tends to produce an acceleration of velocity and shock at the end of the stroke, which, in general, can only be prevented by means which reduce the efficiency of the engine.

In a very early water-pressure engine of Trevitheck's the piston valve was made less in length than the width of the port, so that for a short period the supply pipe was directly open to the exhaust, the flow being gradually arrested by wire-drawing as the valve closed. This involves very great waste. In later engines the valve closes somewhat gradually toward the end of the stroke, so as to retard the flow. But the resistance thus created absorbs and wastes most of the kinetic energy of the water in the supply pipe.

We diminish the difficulty due to the inertia of the moving mass of water by very much restricting its velocity. It is mainly on account of the inertia of the water that, while steam-engines are run at 400 to 600 feet of piston-speed per second, water-pressure engines are rarely run at more than 60 to 80 feet per minute.

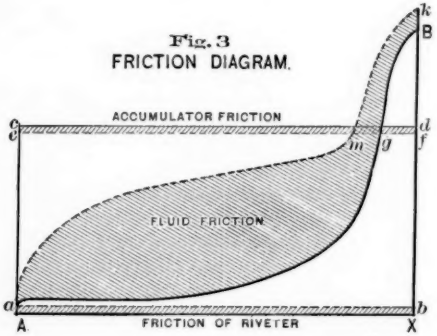
There are certain cases in which the friction and inertia of the fluid, which in most cases are prejudicial, render essential service in the working of the machine. The friction increasing as the square of the velocity acts as a brake in preventing the velocity from becoming excessive, and the diminution of the effective effort at the beginning of the stroke, and its increase at the end of the stroke, which is due to the inertia of the fluid column, is extremely advantageous in certain operations.

All members of this Institution will be acquainted with Mr. Tweddell's admirable hydraulic riveting and punching machinery. It is well known that those machines work not only very efficiently in the sense of doing their work well, but they work with a smaller expenditure of power than machines driven by gearing. That is due partly to saving the friction of the gearing, but mainly to the fact that the machines make no waste strokes. They do not keep on running while waiting for work. On the other hand, in the actual working stroke there is a proportionately large loss of work.

Fig. 2 shows a diagram from a riveter driven by a differential accumulator through 30 feet of 1-inch pipe. The water in the pipe accelerates and is re-

tarded proportionately to the movement of the riveter ram, and the accumulator weight also accelerates and retards in the same way. Hence, the water in the pipe and the accumulator weight virtually form part of the moving riveter ram. But as the accumulator weight moves six times as fast as the riveter ram, the forces due to its inertia are thirty-six times as great as if it were attached to and moved with the riveter ram; and as the water moves eighty-one times as fast as the ram, the forces due to its inertia are more than six thousand times as great as if the water moved at the same speed as the ram. In this machine, therefore, the virtual weight of the ram which closes the rivet, and which is large area, *amk*B*g*, representing the friction of the water in the 1-inch pipe. In fact, it is this friction which determines the speed of the machine, and keeps it down to the safe limit of 1 foot per second at most. When the friction diagram is added to the diagram of useful work, we see that the unbalanced or stored work in the first half of the stroke *aem* is nearly equal to the excess of work, *mkf* at the end of the stroke, so that the machine comes to rest without any violent shock. Mr. Tweddell's riveter is virtually a 300-ton hammer, controlled by a powerful automatic friction brake. Fig. 4 shows better the work stored in the first part of the stroke and re-stored in the second.

Fig. 3
FRICTION DIAGRAM.



put in motion and stopped every stroke is 300 tons.

To control the movement of such a mass as this, powerful brake-action is necessary, and Mr. Tweddell's brake is supplied by the automatic action of the water-friction.

On looking at the diagram, Fig. 2, it will be seen that the effect of the inertia is to greatly diminish the pressure in the beginning of the stroke, and to increase it above the accumulator pressure at the end of the stroke. That is advantageous in closing the rivet. But a large part of the diagram is missing; apart from friction and inertia, the diagram would be a rectangle A*cd*X. The actual pressure line falls greatly below this. Fig. 3 shows an estimate of the friction. There are two rectangles, A*ab*X and *ecdf*, showing the uniform friction of the cup leathers of the riveter and accumulator rams, and there is a surprisingly

III. Turbines.

There are motors, of which the undershot wheel is an old type and the turbine a modern type, in which the head is allowed to take the third form before acting on the motor. On undershot wheels and turbines the water acts in virtue of its velocity. Let the water acquire a velocity due to the head in a given direction. Then the water, by its inertia, opposes change of velocity and direction. In the class of wheels now discussed, the water gives up its energy through this action of its inertia. We have now to study under what conditions we can best recover the energy of motion of the water.

Of the whole energy expended by the water on the machine, a part is taken up and utilized, another part is wasted or lost. It is the object of the designer to make the latter part as small as possible,

and it is therefore necessary to consider in what ways this loss or waste of energy may arise.

1st. There is a waste of energy if the water is allowed to break up into eddies or irregular motions. When water breaks up in this way we say there is loss by shock.

2d. The water leaving the machine may carry off with it part of its energy, there is then a waste of unutilized energy. In many motors this loss is a large one. In the class of motors now considered, this energy rejected can be made as small an amount as we please.

3d. In flowing over the solid surfaces of the machine there is what is termed fluid or skin friction. This is really a loss of the same kind as that due to shock, because skin friction arises from the production of small eddies against the roughnesses of the solid surfaces, or from instability in the fluid itself.

There are some smaller losses due to leakage, friction of bearings, and so on, which, for the purpose of this lecture, may be treated as negligible.

Losses due to shock or breaking-up.—If water is poured from a height into a basin, it acquires, in falling, energy of motion. Reaching the vessel, it is dashed about in different directions and broken up into eddying masses. In a short time the friction destroys this irregular motion, and the energy is wasted.

There is generally such a breaking-up of the fluid and waste of energy if the direction of motion or velocity of a fluid stream is abruptly changed.

Let the water be moving along a pipe which changes section abruptly. Then the velocity v_1 in the first part is changed to v_2 in the second. At the abrupt change of section, eddies are continually formed, which carry off part of the energy of the fluid in a useless form. The energy thus subtracted from the energy of translation, and for practical purposes lost, is—

$$\frac{(v_1 - v_2)^2}{2g}$$

For example, if the section of the pipe is doubled, the loss of energy is one-fourth.

So much for abrupt change of velocity. Next, consider abrupt change of direction. To make the problem quite simple, suppose the water flowing round a bent trough ABCD, Fig. 5. At each bend eddies will be formed at the expense of the energy of flow along the surface. Resolve v_1 at A into a component v_2 parallel to AB and a normal component u_1. Then the energy corresponding to u_1 is wasted, and the water proceeds along AB with the velocity v_2. Resolve v_2 at B into a component v_3 parallel to BC, and a normal component u_2. Then u_2 is wasted. Thus, for the whole surface, there is wasted for each pound of water—

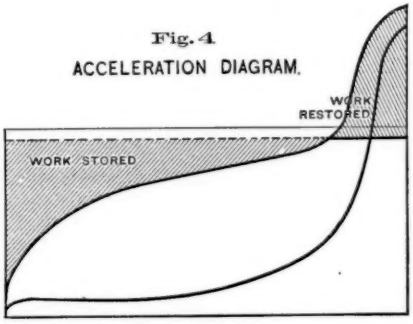
$$\frac{u_1^2}{2g} + \frac{u_2^2}{2g} + \frac{u_3^2}{2g} + \ldots \ldots$$

Now notice the velocities u_1, u_2, u_3, depend on the angles at the bends, and vanish if those angles are indefinitely small. Hence, if the surface is curved throughout, there is no loss due to breaking-up, and the water flows round with its velocity unchanged, except so far as there may be a very small loss, due to the friction of the surface.

Hence the second condition for avoid-

Fig. 4.

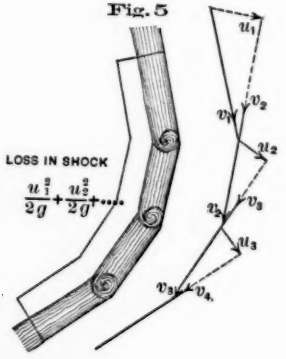
ACCELERATION DIAGRAM.



ing loss in dealing with streams of water is, that the surfaces over which it flows should be gradually and regularly curved.

Generally in hydraulic motors we have to deal with fixed jets of water impinging on moving curved vanes. The condition of avoiding loss due to abrupt change of direction imposes a third very important condition as to the direction of the vane where the jet first impinges. Let AB be the fixed jet of water, BC the moving vane. Let v_1 be the velocity of the jet, and u the velocity of the vane. Resolve v_1 into a component u equal and parallel to the velocity of the vane, and a relative component v_r. Then, if the tangent to the vane at B is parallel to v_r, there is no change of direction when the water first

Fig. 5



impinges on the vane, and no loss due to eddies or breaking-up.

These three conditions—gradual change of section, gradual change of the curvature of the surfaces, and the inclination of the receiving edge of the vanes in the direction of relative motion—can always be satisfied, and hence there need be no loss in an hydraulic motor, due to the shock or breaking up of the fluid.

The two other sources of loss in an hydraulic motor, the energy carried away, and the skin friction against the surfaces of the motor are not so easily disposed of. We can, indeed, reduce the energy carried away almost as much as we please. If there were no skin friction, turbines might have any efficiency short of 100 per cent. The energy carried away in good turbines is often not more than 6 per cent. But it might be reduced to 3 per cent. or 1 per cent., only in doing this, we should in general, seriously increase the loss from skin friction.

It is this loss from skin friction which regulates the proportions of turbines, and which compels us to use, in many cases, small and high-speed turbines on high falls. The writer erected a 70-H. P. turbine on 250 feet fall, with a wheel, 15 inches in diameter, making 1500 revolutions per minute. The skin friction of the disks of this turbine probably amounted to 4 horse-power. If the diameter had been doubled to reduce the speed to 750 revolutions, the skin friction would probably have amounted to 16 horse-power.

Before considering the more complex case of turbines, it will be convenient to examine one or two simpler cases in which these principles are applied.

Consider first, the old form of undershot water-wheel. The water issuing under a sluice with nearly the whole velocity due to the head, strikes the radial floats. There is a loss due to breaking-up, and as the water flowing away cannot have a less velocity than the wheel, there is a large amount of energy rejected. Under the best conditions when the wheel has half the velocity due to the fall, 25 per cent. is lost by shock, and 25 per cent. rejected into the tail race. So that apart from the losses by friction and leakage, an undershot wheel utilizes less than half the energy of the fall.

Many years ago General Poncelet recognized the causes of loss in the ordinary undershot wheel, and constructed the well-known Poncelet wheel. I pass over this to examine another less known example of a wheel of this type.

If a jet strikes a hollow cup, larger than itself, there is little loss due to breaking-up, the jet spreading symmetrically. The water spreads with the relative velocity $V-v$, which is reversed in direction at the lip and become $-(V-v)$, so that the absolute velocity of discharge is $-(V-v)+v=2v-V$. By making $v=\frac{1}{2}V$, the water leaves the cup with no energy left, that is, all the energy of the jet is expended on the cup.

Now, to supply the placer mines in California, canals or "ditches" have been built high on the slopes of the Sierra Nevada. These deliver water at an elevation of 1,000 to 3,000 feet above the great valley of California. In many cases the

mines have been exhausted or abandoned, and hence, has arisen the idea of using the water-power, amounting in the aggregate to several hundred thousand horse-power for mills or quartz crushing.

The fall is here excessively great, and if it were attempted to use turbines, especially those forms most in favor in America, there would be the inconvenience that the turbines would run at an immoderate, and in some cases, an unmanageably great speed. This has the double disadvantage of involving great wear and tear, and of requiring a large amount of gearing, with its concomitant frictional waste.

About twenty years ago there was introduced, a form of impact wheel, which, with American talent for nicknames, was called the Hurdy-Gurdy. It consisted of a wheel of considerable diameter, with a series of cast-iron floats, 4 to 6 inches wide on the face. A jet of water of very small diameter (three-eighths of an inch sometimes) was allowed to strike the vanes normally. Theory shows that in this case the wheel should run at half the speed of the jet, and that the efficiency, even apart from friction, could not exceed 50 per cent. Practical experience also showed that the wheel should have half the velocity of the jet, and the efficiency was found, by experiment, to be 40 per cent. In spite of the low efficiency, such wheels seem to have been useful, partly, because they were cheap and free from liability to accident, but mainly, probably, because by choice of diameter of wheel, any convenient speed of rotation can be obtained.

It is easy to see that the efficiency could be improved by substituting cups for flat floats, and this is what has actually been done. The favorite wheel now is a wheel termed the Pelton wheel, the floats of which are simply cups which deviate the water backwards. A wheel of this kind, working to 107 horse-power, under a head of 386 feet, is said to have given an efficiency of 87 per cent. Without accepting exactly this figure, I see no reason why, with a very high fall, an efficiency of 80 per cent. at all events, should not be reached.

At the Idaho mines, seven of these Pelton wheels have recently been erected to work to about 320 horse-power, driving machinery previously driven by steam. The water is brought a distance of 9,000 feet, in a thin wrought-iron riveted main, 22 inches in diameter. The total head is 542.6 feet, reduced by friction in the main to an effective head of 523 feet. The nozzles by which the water is delivered to the wheels are from $\frac{1}{16}$ to $1\frac{5}{16}$ inch in diameter, and the power is taken from the wheels by 2-inch manila ropes in grooved pulleys, the cost of the change from steam to water-power was between £10,000 and £11,000. The wheels work with hardly any attention or wear, and are believed to give 80 per cent.

The Jet Reaction Wheel or Scotch Turbine.

There is a very simple form of reaction wheel, which forms a convenient step towards a true turbine. In this the water enters the center of the wheel, spreads radially, and issues in jets tangentially to the direction of revolution. The water issues under the head h due to the fall and $\frac{v^2}{2g}$ due to the centrifugal force of the mass of water in the wheel. Let V be the velocity of the wheel, then the velocity of the water through the orifices is

$$v = \sqrt{2gh + V^2}$$

and the backward velocity of the water at the jets is

$$v - V = \sqrt{2gh + V^2} - V$$

It is obvious that this approaches zero as V approaches infinity. For any smaller speed, part of the energy of the fall is rejected into the tail race in the backward motion of the water. Taking friction into account, the best speed of the wheel is the velocity due to the head, and then about 17 per cent. of the energy is carried away, and another 10 or 15 per cent. is lost in friction.

Now, it was the study of the source of the waste of energy in this wheel which led Fourneyron to the invention of the turbine. Fourneyron perceived that in order to avoid the loss due to the backward velocity of discharge, an initial forward velocity must be given to the water. By putting the water in rotation forwards by fixed guide-blades before it enters the revolving wheel, the backward velocity of discharge can be made as small as we please, and then the efficiency of the turbine may approach 100 per cent. as nearly

as we please, apart from the frictional losses, which can in no case be prevented.

The Scotch turbine would, from its simplicity, be still used in certain cases, but for two serious practical defects. One is, that it is the most unstable in speed of all turbines; the other is, that it admits of no efficient mode of regulation for a variation of water-supply.

At the beginning of this century there existed a number of horizontally rotating water-wheels, driven by jets of water or by rotating masses of water, which acted on them chiefly by their inertia. The efficiency of these was very low. In some treatises, especially those of Euler, there were indications of the true principles of construction of such a motor. But it was M. Fourneyron, in 1827, who first realized a practical turbine. M. Fourneyron received the prize of 6,000f. for his invention from the Société d'Encouragement. His turbine is still sometimes constructed with very little modification, and its essential features are present in turbines of all constructions.

M. Fourneyron perceived that if the water was to leave the wheel without any backward velocity, that is, without carrying away and wasting energy, the water must have given it some initial forward velocity before entering the wheel, and his invention mainly consisted in the introduction of guide-blades to give that initial forward velocity.

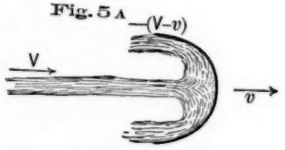
In the Fourneyron turbine, the water descending into the center of the wheel is put into rotation by the guide-blades, and passes into the wheel with a velocity rather less than that due to the head. It passes through the wheel radially and outwards, and hence the Fourneyron turbine is called an outward-flow turbine. The great defect of the Fourneyron turbine is the practical difficulty of constructing any good form of sluice for regulating the power of the turbine. With the cylindrical sluice ordinarily used between the guide-blades and wheel, the efficiency falls off rapidly as the supply of water is diminished; and it is this practical difficulty which I think is leading to a general abandonment of the Fourneyron turbine.

The Fourneyron turbine was soon succeeded by the Jonval turbine, in which the water flows parallel to the axis of the turbine. The Fourneyron turbine works best above the tail water. The Jonval turbine has the advantage that it can be placed below the tail water, or at any height less than thirty feet above it with a suction pipe. But its sluice arrangements are even worse than those of the Fourneyron turbine.

Lastly, Professor James Thomson introduced an inward-flow turbine, in which the water flows radially inwards and is discharged at the center of the wheel. The greatest advantage of this arrangement is that a perfect system of movable sluices or guide-blades can be adopted to regulate the power of the turbine, there being ample space to arrange these outside the wheel.

There are, therefore, outward flow, inward flow, and axial or parallel flow turbines. To these must be added a form used by the late Mr. Schiele, in which the water flows inwards radially and afterwards axially, the wheel vanes being prolonged nearly to the center of the wheel, and which may be called a mixed-flow turbine.

Fig. 5A



Now, in all these turbines, and in all modifications of them constructed for many years, a peculiarity of proportion originally adopted by M. Fourneyron was followed. Instead of allowing the water to issue from the guide-blades with the whole velocity due to the head, he so proportioned the passages that there was a more or less considerable pressure in the space between the guide-blades and wheel. All these turbines are therefore pressure turbines—that is, turbines in which the water enters the wheel under pressure.

To maintain this pressure properly two conditions are necessary—the wheel passages must be completely filled with the stream of entering water, and consequently the wheel must receive the water continuously over the whole circumference simultaneously. These are therefore turbines with complete admission.

M. Girard was the first to perceive

clearly the advantage of departing from Fourneyron's practice. M. Girard constructed turbines in which the water issued from the guide-blades with the full velocity due to the fall, and therefore with no pressure. The wheel must be placed entirely out of the tail water, so that the issuing water is freely deviated on the curved vanes of the wheel. Nearly the whole energy of motion of the water, less the loss in friction, is given up to the wheel. Turbines of this kind are called turbines of free deviation or impulse turbines.

Impulse turbines may be inward, outward, or parallel flow turbines, but they are very commonly outward flow. For normal conditions of working they are slightly less satisfactory than pressure turbines, but they have two very great practical advantages.

In a pressure turbine there must be a definite rate of flow through the wheel to maintain the exact distribution of pressure in the wheel for which it is calculated. If the guide-blade passages are partially closed, the distribution of the hydraulic pressure is completely altered, and the efficiency reduced. In the turbine of free deviation, on the other hand, there is no possible change of pressure in the wheel, for it is all open to the air. Each particle of water following the curve of the wheel-vane acts by itself alone without any interference from its neighbors. Hence, if the guide passages are partially closed, the stream on the wheel is rendered thinner, but its efficiency is in no way impaired. Hence the regulation of the Girard turbine is in general far more perfect than in a pressure turbine.

Classification of Turbines.

I.—*Impulse Turbines.*

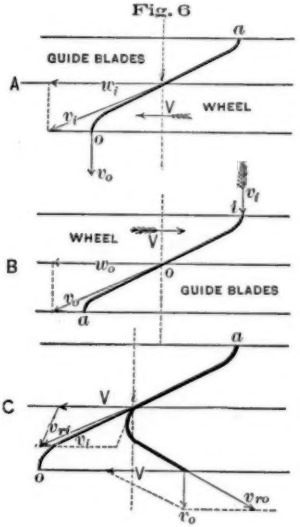
Wheel passages not filled.
Free deviation.
No pressure between guide passages and wheel.
Discharge above tail water.
a. Complete admission.
b. Partial admission.
Axial, inward or outward flow.

II.—*Pressure or Reaction Turbines.*

Wheel passages filled.
Pressure between guide-blades and wheel.
Discharge above tail-water (outward flow); or below tail-water (parallel or inward flow); or into suction pipes (parallel or inward flow).
Always complete admission, axial, inward, outward, or mixed (inward and downward) flow.

To simplify the consideration of the action of the water in a turbine, suppose that for a turbine wheel moving circularly

Fig. 6



we substitute a turbine rod moving in a straight line.* We can pass to the case of the wheel easily afterwards. To be definite, suppose the water flowing vertically downwards, and the rod (Fig. 6, A) moving horizontally from right to left. To give the initial necessary forward velocity the water must be deflected in some path *a i* by fixed guide-blades. Entering the wheel, it produces pressure due to deviation by the wheel vanes, and traverses a path, *i o*, leaving the wheel finally with a much reduced velocity in a direction normal to the surface of discharge.

A simple application of Newton's second law of motion gives at once the force driving the wheel. The water enters the

* The development of a section of an axial flow turbine has always been treated in this way, but the use of a turbine rod as the first step in designing any turbine is due to Von Reiche.

wheel with the initial velocity v_i, which has the horizontal component w_i, and leaves the wheel with a velocity which has no horizontal component. Each pound of water per second, therefore, loses the horizontal momentum $\frac{w_i}{g}$, and since impulse is equal to change of momentum, the horizontal pressure on the wheel is

$$\frac{w_i}{g} \text{ lbs.}$$

for each pound per second flowing through the wheel, and the useful work done in driving the wheel is

$$\frac{w_i V}{g} \text{ foot-lbs. per second.}$$

But the whole energy of gravity on each pound of water falling H feet is H foot-pounds. Hence, if η is the efficiency,

$$\eta H = \frac{W_i V}{g}.$$

This is the fundamental equation on which the whole design of turbines depends. It gives the relation between the original whirling velocity of the water and the velocity of the wheel.

I stop for a moment to point out that exactly the same result is arrived at if the position of the wheel and guide-blades is inverted as in Fig. 6, B. Then the water having no initial forward momentum gains the momentum $\frac{w_o}{g}$ in the wheel, and the equation becomes

$$\eta H = \frac{w_o V}{g}.$$

In applying this formula, the fall H is the effective fall—that is, the fall after deducting any losses in the supply-pipe tail-race, etc., which are extraneous to the turbine. From the work ηH really utilized by the turbine, an additional small loss occurs in the transmission, from friction of the shaft, friction on the wheel-covers and friction of gearing.

It is now to be seen what forms the guide-blades and wheel-vanes must have to direct the water in the absolute path chosen for it.

The guide-blades, being fixed, have exactly the form of the chosen water paths *a i*, Fig. 6, A, or *o a*, Fig. 6, B. But the wheel-vanes have a quite different form from the water-path, because as water moves along that path the wheel also is moving.

In order that the water may enter the wheel without shock, the first element of the vane must be parallel to v_{ri}, Fig. 6, C, the direction of relative motion. In order that the final velocity of the water may be vertical, the last element of the wheel-vane must be parallel to v_{ro}, obtained by compounding the final velocity v_o with the velocity V of the wheel. Having obtained the tangents to the two ends of the wheel-vane, any smooth curve joining these two will satisfy the necessary conditions for the proper action of the water.

Fig. 7

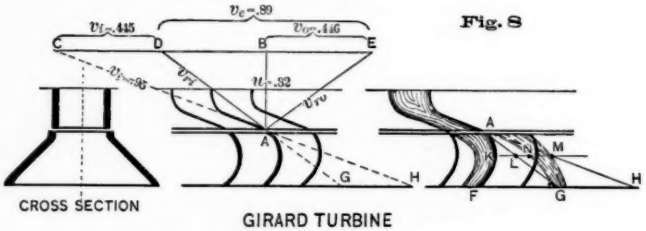


Fig. 8

GIRARD TURBINE

h=29.5;
$\sqrt{2gh}$=43.6;
η=0.89²=0.79.

Turbine Rod Corresponding to a Girard or Impulse Turbine.

In the Girard turbine there is no pressure in the clearance space, and therefore the water issues from the guide-blades

with the velocity due to the effective fall. In the diagram

$$v_i = 0.95\sqrt{2gH}$$

which allows for the friction of the guide-blades.

Next decide what energy shall be rejected into the tail-race. Suppose this is put at 10 per cent., the velocity corresponding to one-tenth of the fall is

$$u = 0.32\sqrt{2gH}.$$

Draw now the triangle of velocities CAB, so that u is the vertical component of v_i. Then CA is the direction in which the water enters the wheel.*

Bisect CB in D. Then CD is the proper velocity of the wheel, and AD is the direction of relative motion of the water and wheel, and tangent to the first element of the wheel-vanes.

In an impulse turbine the relative velocity remains unchanged. Set off BE = the velocity of the wheel, then AE, which obviously by construction is equal to DA, is the direction of relative motion of the water leaving the wheel, and the tangent to the last element of the wheel-vanes.

We have now determined all three angles necessary for drawing the guide-blades and wheel-vanes.

Further, since the relative velocity v_{r1} is changed to v_{r0} in passing through the wheel, therefore DE or V_e is the velocity utilized in the wheel. Hence the work utilized is

$$\frac{V_e^2}{2g},$$

and the efficiency of the wheel is $0.89^2 = 0.79$, apart from those losses which are extraneous to the turbine itself.

To secure the free deviation of the water on the wheel-vanes, and to prevent the choking of the wheel-passages, it is usual to flare out the wheel, as shown in the cross-section. Very commonly the ratio of the inlet and outlet widths is as 4 to 7.

Every datum for the turbine which depends on hydraulic considerations has therefore been determined. And anyone who has mastered this very simple diagram, and who has the requisite general mechanical knowledge, can design a turbine, I need not say as well as I could, but as well as M. Girard himself could.

In drawing the stream of water on the vane it is merely necessary to remember that the relative velocity is constant, and therefore the thickness of the water-sheet is inversely as the width of the bucket.

It is useful to examine the exact absolute path of the water in the wheel, which is easily obtained. If there were no wheel-vanes the water would traverse the absolute path AH and the relative path AG. But the wheel-vanes deviate the water the distance LK from AG. Set off MN = LK, then N is a point in the absolute path. Any number of such points can be found and the absolute path drawn. Or conversely, if the absolute path is chosen the wheel-vane can be drawn. The wheel-vanes will be of good form if the absolute path shows a continuous and tolerably uniform curvature, and if the water stream through the wheel is a converging rather than a diverging one.

Turbine Rod Corresponding to a Pressure Turbine.

In a pressure turbine the wheel passages are always full. Hence the velocity of flow, that is, the vertical component of the waters' velocity in the diagram is constant, or at all events is determinable from the general dimensions of the wheel. That velocity is, therefore, the velocity at which the water is rejected into the tail-race. This ought to be small; it is very often only $\frac{1}{5}\sqrt{2gH}$, but to make the diagram clearer, I have taken it at $0.27\sqrt{2gH}$, in which case 7 per cent. of the energy is rejected.

Further, 8 to 15 per cent. of the energy is wasted in friction. Taking the extreme case—suppose 15 per cent. wasted in friction; then there remains 78 per cent. to be utilized in the turbine, and the velocity due to 78 per cent. of the head is 0.88 of the velocity due to the head.

In a pressure turbine this 78 per cent. of the energy is partly used in producing the initial horizontal velocity, and partly in producing the pressure in the clearance space. It is optional how this division is made. In the figure the velocity 0.88 is divided into a horizontal com-

* It is assumed here that the velocity of flow through the wheel, u, is constant. If it is not so, the figure must be drawn with the actual values.

ponent $w_i = 0.66$, and a vertical component $v_p = 0.589$. Hence, if the initial horizontal velocity is taken at $0.66\sqrt{2gH}$, the velocity corresponding to the pressure in the clearance space will be $0.589\sqrt{2gH}$.

Setting off the assumed vertical velocity 0.27, and the just found horizontal velocity 0.66, we get the initial velocity and direction of motion of the water $v_i = 0.71\sqrt{2gH}$, and determine the angle γ of the guide blades.

To determine the proper velocity of the wheel, I shall apply the principle of momentum. As the water enters the wheel with the horizontal velocity $w_i = 0.66\sqrt{2gH}$, and leaves with no horizontal momentum, the effective horizontal pressure of each pound of water on the wheel is

$$\frac{w_i}{g} \text{ lbs.}$$

and if V is the velocity of the wheel, the useful work done is

$$\frac{w_i V}{g} \text{ ft.-lbs. per pound of water.}$$

But 78 per cent. of the energy due to the head is utilized so that

$$\frac{w_i V}{g} = 0.78\ H,$$

which gives

$$V = 0.78\frac{gH}{w} = 0.78\frac{gH}{0.66\sqrt{2gH}}$$

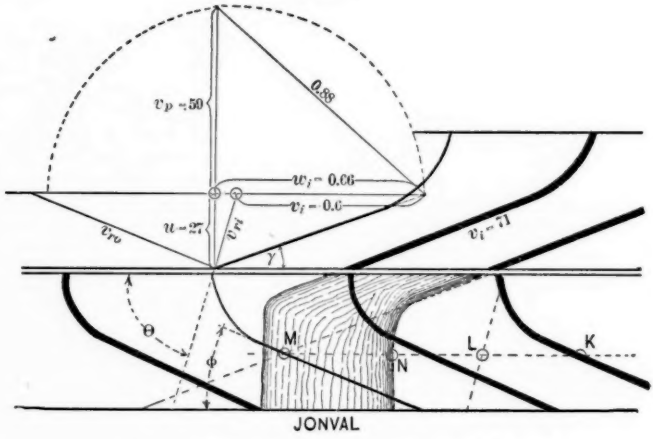
$$V = 0.6\sqrt{2gH}$$

Knowing V and v_i, we have now the direction of relative motion where the water enters the wheel, and the angle θ of the first element of the wheel-vanes.

Similarly combining u and V, we get the relative velocity v_{ro} at the point of discharge, and the angle φ at the other end of the wheel-vanes.

It is easy to show that the utilized velocity 0.88 is the chord of a semi-circle, of which the velocity V of the wheel is the radius, so that the velocity of the wheel is easily found graphically and without calculation.

Fig. 9.

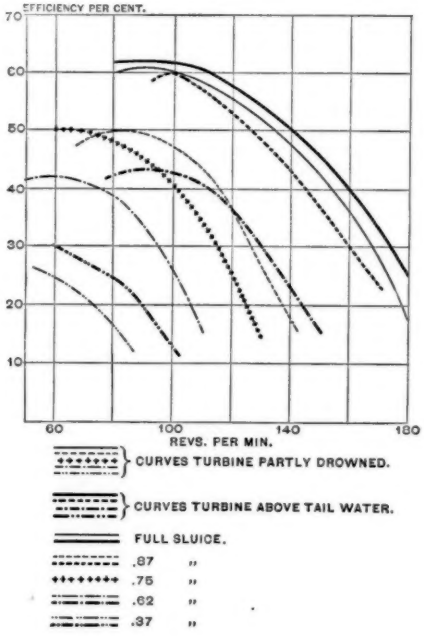


Transformation of the Turbine Rod into an Inward or Outward Flow Turbine.—It is not difficult to proceed by methods similar to those already described to draw directly the path and the curves of the vanes of a radial flow turbine. But the proceeding is complicated by the circular motion, and a more simple method is available. If we draw a turbine rod for any given case first, the corresponding inward or outward flow turbine can be obtained by simple geometrical projection.

Draw circles at the same distances

apart as the edges of the guide-blades and wheel in the turbine rod. Subdivide the spaces of the turbine rod by lines at equal distances, and the spaces of the turbine by corresponding equidistant circles. Thus let the circle *b* correspond to the line *b* in the turbine rod. Project the point where *b* intersects the wheel-vane to the circle *a*, and draw a radius. Where this intersects the circle *b* is the corresponding point on the wheel-vane curve. The guide-blade and absolute water-path are projected in the same way.

Fig.10



Efficiency of Turbines.—The largest waste of energy in turbines is due to fluid friction, and this cannot be estimated with any great accuracy, and can only therefore be determined by experiment. There are a number of experiments, too carefully carried out and too accordant to be put aside, which show that turbines of very different types, well constructed, and working in the best conditions, yield an efficiency little, if at all, inferior to 80 per cent. A very few experiments, apparently also reliable, show an efficiency slightly greater. But allowing for the probabilities of error in water measurement, I think that 80 per cent. may be taken as the maximum efficiency of the best turbines in normal conditions of working.

While I do not believe that this efficiency is likely in any case to be exceeded, I believe also that any one of the ordinary types of turbine will, within a very small range of difference, yield the same efficiency. The search of inventors, especially in America, for some new modification of the turbine, which shall have a greater maximum efficiency, I believe to be altogether a chase of the philosopher's stone, and not likely to end more successfully than that of the Rosicrucians.

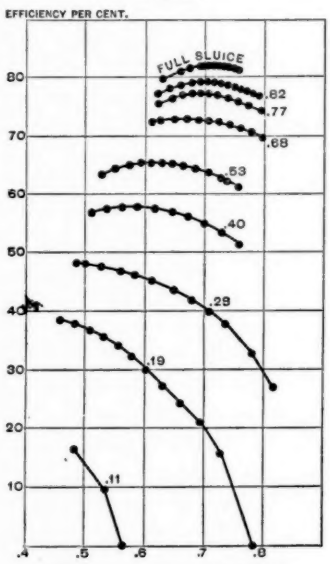
The statements that this turbine or that has attained 82 or 83 or 85 per cent. of efficiency are not only delusive, they are extremely misleading. The probability is that the small extra percentage of maximum efficiency claimed over that

of other turbines is due to error of water measurement. But even if this is not the case, the real practical value of a turbine is not measured by its maximum efficiency when everything has been arranged to suit it, but by the average efficiency in the varying conditions of fall, water-supply, speed, and work to be done, in which it has actually to operate. Now, there is one condition, at all events, which in most turbines is constantly varying. The supply of water varies either from actual deficiency in the supply, or because the work to be done varies. In either case the quantity of water discharged through the turbine varies. To effect this alteration of discharge, turbines are provided with sluices or regulating apparatus. In nearly all cases the use of the regulating apparatus seriously diminishes the efficiency of the turbine, so that the average efficiency is very much lower than the maximum efficiency. In the mode of regulating different turbines, there are differences far more important than any difference of type or mode of action. Before discussing the efficiency of turbines under regulation, there is a preliminary point to clear up.

Some eighteen years ago I plotted the curves shown in Fig. 10, giving the efficiency of a Fourneyron turbine, with different sluice openings and at different speeds. There are two sets of experiments, shown by darker and thinner lines, corresponding to the normal condition for a Fourneyron out of water, and to the case where the turbine was partly drowned. Roughly, the greatest efficiency, when the turbine was not drowned, was 62 per cent. with full sluice, 60 per cent. with seven-eighth sluice, 43 per cent. with five-eighth sluice, and only 30 per cent. with three-eighth sluice. With the turbine drowned the efficiencies were lower.

For each set of experiments the efficiency is greatest for a given speed of the turbine. But, unfortunately, the speed of greatest efficiency is not the same for different openings of the sluice. With full sluice the efficiency is greatest at about one hundred revolutions. But with three-eighth sluice the efficiency is greatest at sixty revolutions or less. Now, generally the speed of a turbine depends on the work to be done, and cannot be adjusted to suit hydraulic requirements. If the speed has to vary, as in pumping, with the demand for water, the speed will very commonly differ from that which suits the turbine best, and the efficiency will not, on the average, reach the maximum value. Still more commonly, a turbine has to drive machinery at a very nearly constant speed. Naturally we choose for that speed the speed of greatest efficiency with full sluice. But then, for that speed, the efficiency falls off much more rapidly with the closing of the sluice than I stated before.

Fig.11



Speed in fraction of $\sqrt{2gh}$.

Fig. 11 shows the results of a very extensive series of experiments on the Humphrey turbine, carried out by Mr. Francis at Lowell. The turbine is of 275 horse-power, on 13 feet fall. The experiments were independent of the manufacturers, and the arrangements for water measurement and power measurement were as good as possible. They show the rapid falling off of the efficiency as the sluice closes, and the diminution, at the same time, of the speed of greatest efficiency. The fraction of sluice open is printed against each curve.

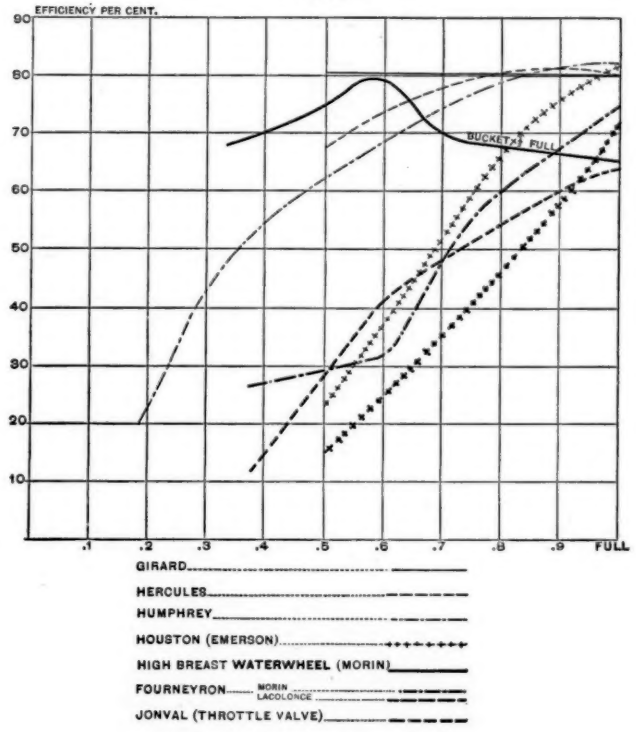
Fig. 12 shows the efficiency of differ-

ent types of turbine for different openings of the sluice, and always for the speed of greatest difficulty with full sluice, and is intended to indicate the importance of adopting a good method of regulation.

The worst mode of regulation of all, though it is still frequently used, is to put a throttle valve in the supply pipe.

The curves for the Hercules and Humphrey turbine show results, I believe, as good as any reliable results obtained in America, the latter being, perhaps, the most reliable, because the experiment was made by Mr. Francis, whose experience in measuring water by weirs is probably greater than that of any other engineer.

Fig. 12



A throttle valve acts entirely by creating a prejudicial resistance, or by destroying part of the effective head.

Next worst to this, perhaps, is the form of sluice adopted in the Fourneyron turbine, a circular cylinder which slides in the clearance space. It is obvious that, when the stream entering the wheel is narrower than the width of the wheel, there must be a general breaking up of the stream, and a complete alteration of the conditions of pressure and velocity for which the wheel curves are designed.

The sluice arrangements in American turbines do not seem, from the theoretical point of view, particularly good; but although American makers do not explain the principles on which they proceed, I suspect that in these turbines some approach is made towards the condition of free deviation, in which case the defects of the sluice produce a less unfavorable effect.

For pressure turbines, only one approximately perfect mode of regulation has ever been adopted, and that is the

movable guide-blades of Professor James Thomson. With this arrangement the water enters the wheel over its whole circumference and depth, with its velocity and direction little changed, in all positions of the guide-blades. The only objection to this mode of regulation is that it involves a certain amount of mechanical complication.

For Girard turbines with partial admission, the mode of regulation is simple, and perfectly complies with theoretical conditions; the width of the stream entering the wheel is altered without in any way affecting the perfect action of the water in the wheel.

On Prince Bismarck's estate at Varzin, three considerable factories worked by turbines have been erected. In the first, in which considerations of capital expenditure were the ruling ones, the turbines were guaranteed to give only 60 per cent.; in the second, 70 per cent.; and in the third, to which I am now referring, the turbines were guaranteed by the makers to give 75 per cent. with full sluice and 70 per cent. with half sluice. If this guarantee was not satisfied, the turbines were to be removed without recompense by the makers. These turbines were Girard turbines, and to ascertain whether the conditions of the contract were satisfied, an extremely careful series of experiments were made, the supervision of which was confided to Professor Zeuner, one of the most distinguished professors of mechanical science in Europe. There are two turbines, each of about 200 horse-power, on about 12 feet fall. The general result of the experiments was that the efficiency of the turbines was 0.795 with full sluice, and 0.801 with the sluices half closed, and with the same turbine speed in both cases. These results are the means of four trials in each case, which varied extremely little from one another.

The most careful estimateof the separate losses of work in a turbine which I have met with is that made by Mr. Lehmann. He has analyzed experiments on thirty-six turbines, varying from 1 to 500 horse-power, and has estimated the average losses of energy from various causes as follows:

Loss per cent. due to.....	Axial flow. Turbine.	Outward flow. Turbine.	Inward flow. Turbine.
Hydraulic resistances.....	12	14	10
Unutilized energy.....	3	7	6
Shaft friction.....	3	2	2
Total.....	18	23	18
Efficiency	0.82	0.77	0.82

I shall be told—especially by users of turbines in this country—that there are numerous cases of failures of turbines; of turbines which are not giving satisfaction, or which, if they are doing their work, are using an extravagantly large amount of water. There is, no doubt ground for these complaints; but the reason is not far to seek. Turbines are too often built by manufacturers without adequate hydraulic knowledge. The continued construction of turbines with thoroughly bad systems of regulation is a proof of the want of such knowledge. But most often the turbine fails from quite another cause. No adequate preliminary inquiry is made as to the local conditions in which a turbine is to be placed. Some previously manufactured size of turbine is selected and put in, with very little regard to the precise conditions in which it is to work. The variations of the fall, and the variations of the water supply are neither of them determined. Naturally it results that the proportions of the turbine are unsuitable, and the turbine is blamed, instead of its constructors.

American Turbines.—There is an opinion in some quarters that the best turbines are now American turbines. I should be sorry to underrate the value of American experience in turbine building, but on one point I can speak confidently,

There is nothing new in principle in any American turbine. The Americans adopted in turn the Fourneyron, the Jonval, the inward-flow, and the mixed-flow turbines, and, so far as I can see, they have copied, without any material change, the turbines of Europe. There are amongst American turbines some so mal-constructed that they look as if they had come from the region behind the looking-glass. Others, no doubt, are excellent; but where they are best they most nearly approach ordinary European patterns. Many American turbines are mixed-flow turbines. This type of turbine is probably the cheapest to construct of all the pressure-turbines, and, like the inward-flow, permits a good mode of regulation. But there is absolutely no advantage in the efficiency to be got by twisting the water round a vane of double curvature, over that which can be got with a vane of simple curvature. In their purely practical aspect, the best American turbines are excellent. They are well manufactured, and attention is paid to designing them so that they can be cheaply erected.

Steam Turbines.—Steam under pressure will work a turbine as well as water under pressure, and with a no great alteration in the methods, a steam turbine can be designed like a water turbine. But there is a practical difficulty in the way of the adoption of steam turbines not yet overcome. For steam of, say, 30 lbs. pressure, the height corresponding to the pressure is about 60,000 feet. The velocity due to the head is such that the circumferential speed of the turbine must be about 1,000 feet per second. So soon as we can find a material strong enough and durable enough to stand an excessive speed of that kind, so soon we may have steam turbines much smaller and cheaper, and not less efficient than ordinary steam-engines.*

* The account of the Pelton wheel is from a paper by Mr. Hamilton Smyth in the Proc. Am. Soc. Eng.

MINERAL PRODUCTS OF THE UNITED STATES.

THE second report on "The Mineral Resources of the United States," by Albert Williams, Jr., Chief of the Division of Mining Statistics and Technology, United States Geological Survey, is now in press, and will be issued shortly. This report is for the calendar years 1883 and 1884, and contains detailed statistics for these periods, and also for preceding years, together with much descriptive and technical matter. The following are the totals of the production of the more important mineral substances in 1884:

Coal.—The only statistics in which the trade is interested are those relating to the amount of coal which is mined for and reaches the market. There is, besides, a local and colliery consumption which is usually disregarded in statistics, and which ranges from 5 to 6½ per cent. of the total shipments. Of what may be called the commercial product, the quantities in 1884 were as follows: Pennsylvania anthracite, 30,718,293 long tons; bituminous and brown coal, lignite, and small lots of anthracite mined elsewhere than in Pennsylvania, 66,875,772 long tons; total, 97,594,065 long tons. The spot value of the commercial product was: Pennsylvania anthracite, $61,436,586; bituminous and all other coals, $70,219,561; total, $131,656,147. Including the local consumption, etc., the the total product in 1884 may be stated at 106,906,295 long tons, namely, 33,175,756 long tons of Pennsylvania anthracite, and 73,730,539 long tons of bituminous and all other coals; and the value at the mines was: Pennsylvania anthracite, $66,351,512; bituminous and all other coals, $77,417,066; total, $143,768,578. The total production (that is, including colliery and local consumption) of anthracite was 1,160,713 long tons less than in 1883, while its value was $10,905,543 less, the disproportionate decline in value being due to a fall of 25 cents per ton in spot price ($2.25 to $2). The total bituminous coal production increased 5,199,039 long tons over that of 1883, but its value was $4,820,734 less,

the average valuation at the collieries having fallen from $1.20 to $1.05. The total output of all coals showed a net gain in tonnage of 4,038,326 long tons, and a decline in value of $15,726,277.

Coke.—There were 4,873,805 short tons of coke made in 1884, worth $7,242,878 at the ovens. This production consumed 7,951,974 short tons of coal. The amount of coke made was 590,916 tons less than in 1883, and the value was $878,729 less.

Petroleum.—The production of crude petroleum in 1884 was 24,089,758 barrels of 42 gallons each, of which the Pennsylvania and New York oil fields produced 23,622,758 barrels. The total value at an average spot price of 85 cents, was $20,476,294. As compared with 1883 the production was 689,529 barrels greater; but the total value was $5,263,958 less, the average spot price having fallen from $1.10, or 25 cents per barrel.

Natural Gas.—The estimated value of the natural gas used in the United States in 1884 was $1,460,000, as against $475,000 in 1883. The value is computed from that of the coal superseded by natural gas.

Iron.—The principal statistics for 1884 are as follows: Iron ore mined, 8,200,000 long tons; value at mine, $22,550,000. Domestic iron ore consumed, 7,718,129 long tons; value at mine, $21,224,854. Imported iron ore consumed, 487,820 long tons; total iron ore consumed, 8,125,949 long tons. Pig iron made, 4,097,868 long tons, a decrease of 497,642 tons as compared with 1883; value at furnace, $73,761,624, or $18,148,576 less than in 1883. Total spot value of all iron and steel in the first stage of manufacture, excluding all duplications, $107,000,000, a decline of $35,000,000 from 1883. Fuel consumed in all iron and steel works, including blast furnaces, 1,973,305 long tons of anthracite, 4,226,986 long tons of bituminous coal, 3,833,170 long tons of coke, and 62,110,660 bushels of charcoal, besides a notable quantity of natural gas. Limestone used as flux, 3,401,930 long tons; value at quarry, $1,700,965.

Gold and silver.—The Mint authorities estimate the production in 1884 at $30,800,000 gold, and $48,800,000 silver (coining rate); total, $79,600,000. This was an increase of $800,000 gold, and $2,600,000 silver, as compared with 1883. The gold production was equivalent to 1,489,049 troy ounces, and the silver to 37,744,605 troy ounces.

Copper.—The production in 1884, including 2,858,754 pounds made from imported pyrites, was 145,221,934 pounds, worth $17,789,687, at an average price of 12¼ cents per pound in New York City. The amount was 28,070,139 pounds greater than the production of 1883; but the value was $275,120 less than that for 1883, owing to the decline in price. In 1884, 4,224,000 pounds of bluestone (sulphate of copper, "blue vitriol") were made; worth, at 4.3 cents per pound, $181,632.

Lead.—Production, 139,897 short tons. Total value, at an average price of $75.32 per ton on the Atlantic seaboard, $10,537,042. The production was 4,060 tons less than that of 1883, while the decrease in value was $1,785,677. The production of white lead (carbonate) is estimated at about 65,000 short tons, worth, at 4⅞ cents per pound, $6,337,500, almost all of which was made from pig lead. The production of litharge and red lead has not been ascertained.

Zinc.—Production of metallic zinc, 38,544 short tons, worth, at an average price of 4.44 cents per pound in New York City, $3,422,707. The output was 1,672 tons greater than 1883, and the value increased $111,601. Besides the spelter and sheet zinc, about 13,000 short tons to zinc white (oxide) were made directly from the ore, the total value of which, at 3½ cents per pound, was $910,000.

Quicksilver.—Production, 31,913 flasks (of 75½ pounds net=2,441,344 pounds), or 14,812 flasks less than in 1883. Total value, at an average price of $29.34 per flask at San Francisco, $936,327, a decline of $317,305, as compared with the total value of the product of the previous year. During the year, 600,000 pounds of quicksilver vermilion were made, worth $288,000.

Nickel.—Production of nickel contained in copper-nickel alloy, 64,550 pounds, worth, at 75 cents per lb. $48,412; an increase of 5,750 pounds, but a decline of $4,508 in total value, owing to the falling off in price.

Cobalt.—The amount of cobalt oxide

made in 1884 was about 2,000 pounds, as against 1,096 pounds made in 1883. Its value, at $2.55 per pound, was $5,100. The value of cobalt ore and matte cannot be ascertained, as it is chiefly dependent on the nickel contents.

Manganese.—The output of manganese ore in 1884 was about 10,000 long tons, or 2,000 tons more than in 1883. The total value, at $12 per ton at the mines, was $120,000, or about the same as in 1883, the average price having declined $3 per ton.

Chromium.—The production of chrome iron ore, all from California, was about 2,000 long tons, or about two-thirds as much as in 1883. At an average value of $17.50 per ton at San Francisco, the total value was $35,000.

Tin.—A little tin ore was taken out in the course of development work in Dakota, Wyoming, Virginia, and Alabama, but the only metallic tin made was a few hundred pounds from ore of the Black Hills (Dakota) mines made in sample tests at New York City pending the building of reduction works at the mines.

Platinum.—The amount mined in 1884 was about 150 troy ounces, worth, crude, $3 per ounce.

Aluminum.—The amount made in the United States in 1884 was 1,800 troy ounces, an increase of 800 ounces over the production of 1883. At 75 cents per ounce the total value was $1,350.

Building stone.—It is estimated that the value of the building stone quarried in 1884 was $19,000,000, as against $20,000,000 in 1883; the decline being due partly to dullness of trade and partly to the increased use of other structural materials.

Brick and Tile.—The output was about the same as in 1883, but as manufacturers cut down expenses still further, meeting a lower market, the total value is estimated at $30,000,000 as against $34,000,000 in 1883.

Lime.—There were 37,000,000 barrels (of 200 pounds) made in 1884, the average value per barrel at the kilns being not over 50 cents, or $18,500,000. The production was about 5,000,000 barrels greater than in 1883, but owing to the fall in price the total value was about $700,000 less.

Cement.—About 100,000 barrels (of 400 pounds) of artificial Portland cement were made, or 10,000 barrels more than in 1883; the total value, at $2.10 per barrel, being $210,000. The production of cement from natural cement rock was 3,900,000 barrels (of 300 pounds), or 200,000 barrels less than in 1883; worth, at 90 cents per barrel, $3,510,000. The total production of all kinds of cement was about 4,000,000 barrels, valued at $3,720,000.

Precious stones.—The estimated value of American precious stones sold as specimens and souvenirs in 1884 was $54,325, and the value of the stones sold to be cut into gems was $28,650; total, $82,975. About $140,000 worth of gold quartz was saved as specimens or made into jewelry and ornaments.

Buhrstones.—The value of the buhrstones yearly made in the United States is about $300,000.

Grindstones.—Dealers estimate the value of the grindstones made in 1884 at $570,000.

Phosphates.—The production of washed phosphate rock in South Carolina during the year ending May 31, 1884, was 431,779 long tons, worth $2,374,784, or 53,399 tons more than in the previous year, with an increase of $104,504 in value. The average spot price, $5.50 per ton, was 50 cents less than in the preceding year. The recent discoveries of phosphate rock in the adjoining States of North Carolina, Alabama, and Florida will probably lead to a still further increase in production. Of manufactured fertilizers, 967,000 short tons, worth $26,110,000, were made in the year ending April 30, 1884, and 1,023,500 short tons, worth $27,640,000, were made in the year ending April 30, 1885.

Marls.—In New Jersey about 875,000 tons, worth $437,500 at the pits, were dug in 1884. In addition, small quantities were produced for local use in some of the Southern States. The production is declining, owing to competition with fertilizers made from phosphate rock, etc.

Gypsum.—In the Atlantic States, from Maine to Virginia, 65,000 long tons of land plaster and 60,000 tons of stucco, total 125,000 tons, were made in 1884, of which nearly all was from Nova Scotia gypsum. The statistics for Michigan have not been reported, but the produc-

tion did not vary greatly from that in 1883, in which year it was 60,082 short tons of land plaster and 159,100 barrels (of 300 pounds) of stucco. In Ohio, 4,217 short tons of land plaster and 20,307 barrels of stucco were produced. There was also a small production in other parts of the country; but the total amount of domestic gypsum used is not known.

Salt.—The production in 1884 was 6,514,937 barrels of 280 pounds (equivalent to 1.824,182,360 pounds, or 32,574,685 bushels, or 912,091 short tons, according to the unit used). The total value, computed on average wholesale prices at the point of production, was $4,197,734. The apparent output was 322,706 barrels greater than in 1883, while the value was $13,308 less; but the production figures do not include a considerable stock on hand in the Onondaga district, not officially reported because not inspected.

Bromine.—The production is estimated at 281,100 pounds, all from the Ohio and West Virginia salt district; worth, at 24 cents per pound, $67,464.

Borax.—Production about 7,000,000 pounds, or 500,000 pounds more than in 1883. The total value, however, was less than that of the product of 1883, being about $490,000 at San Francisco rates, as against $585,000 in 1883.

Sulphur.—No exact statistics. The production was only about 500 tons, worth about $12,000.

Pyrites.—About 35,000 long tons were mined in the United States, worth about $175,000 at the mines. Some 33,500 tons of imported pyrites were also burned, making a total consumption of 68,500 tons.

Barytes.—Full statistics not received. The production is estimated to have been about 25,000 tons; worth, at $4 per ton, unground, at the point of production, $100,000.

Mica.—The production of merchantable sheet mica, not including mica waste, was 147,410 pounds, valued at $368,525.

Feldspar.—The production was 10,900 long tons, or 3,200 tons less than in 1883. Its value at the quarries was $55,112.

Asbestos.—The amount mined was about 1,000 short tons, worth about $30,000.

Graphite.—Production nominal, the supply being drawn from the stock accumulated in 1883.

Asphaltum.—The annual production is about 3,000 tons, having a spot value of $10,500.

Alum.—About 38,000,000 pounds were made in the United States in 1884, or 3,000,000 pounds more than in 1883. At an average spot value of $1\frac{7}{8}$ cents per pound, the product was worth $712,500.

Copperas.—The amount made in 1884 was 15,500,000 pounds, worth, at 60 cents per hundredweight, $93,000.

Mineral Waters.—The sales of natural mineral waters in 1884 amounted to 68,720,936 gallons, valued at $1,665,490, an apparent increase of 21,431,193 gallons and $526,007 upon the figures for 1883. While the sales are undoubtedly increasing, it is possible that the excess in the reported quantity and value of the waters sold in 1884 as compared with 1883 may be partly due to the greater fullness of the returns for 1884. Besides the waters bottled and placed on the market there is a large local consumption, not included in the foregoing figures.

Totals.—As was remarked in the former report, it is impossible to state the total mineral product in any form which shall not be open to just criticism. It is evident that the production statistics of such incongruous substances as iron ore, metallic gold and silver, the spot value of coal mined and the market value of metallic copper after having been transported hundreds of miles, the spot value of a crude substance like unground, unrefined barytes, and the value of a finished product like brick (in which the cost of manufacture is the leading item), cannot well be taken as items in a general summary. The statistics have been compiled with a view to giving information on those points which are of most interest and utility, and are presented in the form usual in the several branches of trade statistics. The result is that the values stated for the different products are necessarily taken at different stages of production or transportation, etc. Theoretically perfect statistics of mineral products would include, first of all, the actual net spot value of each substance in its crudest form, as taken from the earth; and yet for practical purposes such statistics would have little

interest other than the fact that the items could be combined in a grand total in which each substance should be rated on a fairly even basis. The following groupings, therefore, are presented with a full realization of the incongruity of many of the items. The grand total might be considerably reduced by substituting the value of the iron ore mined for that of the pig iron made, by deducting the discount on silver, and by considering lime, salt, cement, borax, etc., as manufactures. It will also be remarked that the spot values of copper, lead, zinc, and chrome iron ore are much less than their respective values after transportation to market. Still, the form adopted seems to be the only one which admits of a comparison of the total values of the mineral products from year to year.

METALLIC PRODUCTS OF THE UNITED STATES IN 1884.

	Quantity.	Value.
Pig Iron, long tons, spot value	4,097,868	$73,761,624
Silver, troy ounces, coining value	37,744,605	48,800,000
Gold, troy ounces, coining value	1,489,949	30,800,000
Copper, pounds, value at New York City (*a*)	145,221,934	17,789,687
Lead, short tons, value at New York City	139,897	10,537,042
Zinc, short tons, value at New York City	38,544	3,422,707
Quicksilver, flasks, value at San Francisco	31,913	936,327
Nickel, pounds, value at Philadelphia (*b*)	64,550	48,412
Aluminum, troy ounces, value at Philadelphia	1,800	1,350
Platinum, troy ounces, value crude at New York City	150	450
Total	....	$186,097,599

a Including copper made from imported pyrites
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1884 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania..long tons (*a*)	73,730,539	$77,417,066
Pennsylvania anthracite.....do. (*b*)	33,175,756	66,351,512
Petroleum.....barrels	24,089,758	20,476,294
Building stone	....	19,000,000
Lime.....barrels	37,000,000	18,500,000
Salt.....do.	6,514,937	4,197,734
Cement.....do.	4,000,000	3,720,000
South Carolina phosphate rock.....long tons (*c*)	431,779	2,374,784
Limestone for iron flux.....do.	3,401,930	1,700,965
Mineral waters.....gallons sold	68,720,936	1,665,490
Natural gas	....	1,460,000
Zinc white.....short tons	13,000	910,000
Concentrated borax.....pounds	7,000,000	490,000
New Jersey Marls.....short tons	875,000	437,500
Mica.....pounds	147,410	368,525
Pyrites.....long tons	35,000	175,000
Gold quartz, souvenirs, jewelry, etc	....	140,000
Manganese ore.....long tons	10,000	120,000
Crude barytes.....do.	25,000	100,000
Ocher.....do.	7,000	84,000
Precious stones	....	82,975
Bromine.....pounds	281,000	67,464
Feldspar.....long tons	10,900	55,112
Chrome iron ore.....do.	2,000	35,000
Asbestos.....short tons	1,000	30,000
Slate ground as a pigment.....long tons	2,000	20,000
Sulphur.....short tons	500	12,000
Asphaltum.....do.	3,000	10,500
Cobalt oxide.....pounds	2,000	5,100
Total	....	$220,007,021

a The commercial product, that is, the amount marketed, was only 66,875,772 tons, worth $70,219,561.
b The commercial product, that is, the amount marketed, was only 30,718,293 tons, worth $61,436,586.
c Year ending May 31.

RÉSUMÉ OF THE VALUES OF THE METALLIC AND NON-METALLIC MINERAL SUBSTANCES PRODUCED IN THE UNITED STATES IN 1884.

Metals	$186,097,599
Mineral substances named in the foregoing table	220,007,021
	406,104,620
Fire-clay, kaolin, potter's clay, common brick clay, terra-cotta, building sand, glass sand, limestone used as flux in lead smelting, limestone in glass making, iron ore used as flux in lead smelting, marls, (other than New Jersey), gypsum, tin ore, antimony, iridosmine, mill-buhrstone and stones for making grindstones, novaculite, corundum, lithographic stone, talc and soapstone, quartz, fluor spar, nitrate of soda, carbonate of soda, sulphate of soda, native alum, ozocerite, mineral soap, strontia, infusorial earth and tripoli, pumice-stone, sienna, umber, etc., certainly not less than	7,000,000
Grand total	$413,104,620

The *production in* 1884, 1883, *and* 1882 *compared.*—Tables showing the quantities and values of the mineral products of the United States in 1883 and 1882 are appended for comparison. From these it appears that the total value of the metals and minerals produced in 1884 was $39,100,008 less than in 1883, and that the decline in 1883 from 1882 was $3,012,061; that is, the falling off in value began on a small scale in 1883, but was accented in 1884. The net decline as will be seen by reference to the tables, has been due rather to a depression in price than to a decrease in quantity; indeed, several important substances show a decided increase in production, notwithstanding the general dullness of trade. The overproduction, taking the whole field into consideration, has been less than was generally feared.

METALLIC PRODUCTS OF THE UNITED STATES IN 1883.

	Quantity.	Value.
Pig iron, long tons, spot value	4,595,510	$91,910,200
Silver, troy ounces, coining value	35,733,622	46,200,000
Gold, troy ounces, coining value	1,451,249	30,000,000
Copper, pounds, value at New York City (*a*)	117,151,795	18,064,807
Lead, short tons, value at New York City	143,957	12,322,719
Zinc, short tons, value at New York City	36,872	3,311,106
Quicksilver, flasks, value at San Francisco	46,725	1,253,632
Nickel, pounds, value at Philadelphia (*b*)	58,800	52,920
Aluminum, troy ounces, value at Philadelphia	1,000	875
Platinum, troy ounces, value, crude, at New York City	200	600
Total	....	$203,116,859

a Including copper made from imported pyrites.
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1883 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania....long tons (*a*)	68,531,500	$82,237,800
Pennsylvania anthracite.....long tons (*b*)	34,336,469	77,257,055
Petroleum.....barrels	23,400,229	25,740,252
Building stone.....	....	20,000,000
Lime.....barrels	32,000,000	19,200,000
Cement..... do.	4,190,000	4,293,500
Salt..... do.	6,192,231	4,211,042
South Carolina Phosphate Rock.....long tons (*c*)	378,380	2,270,280
Limestone for iron flux.....long tons	3,814,273	1,907,136
Mineral waters.....gallons sold	47,289,743	1,139,483
Concentrated borax.....pounds	6,500,000	585,000
New Jersey marls.....short tons	972,000	476,000
Natural gas.....	....	475,000
Mica.....pounds	114,000	285,000
Pyrites.....long tons	25,000	137,500
Manganese ore.....long tons	8,000	120,000
Gold quartz souvenirs, jewelry, etc.....	....	115,000
Crude barytes.....long tons	27,000	108,000
Precious stones.....	....	92,050
Ocher.....long tons	7,000	84,000
Bromine.....pounds	301,100	72,264
Feldspar.....long tons	14,100	71,112
Chrome iron ore..... do.	3,000	60,000
Graphite.....pounds	575,000	46,000
Asbestos.....short tons	1,000	30,000
Sulphur..... do.	1,000	27,000
Slate ground as a pigment.....long tons	2,000	24,000
Asphaltum.....short tons	3,000	10,500
Cobalt oxide.....pounds	1,096	2,795
Total.....	....	$241,087,769

a The commercial product, that is, the amount marketed, was only 65,268,095 tons, worth $78,321,714.
b The commercial product, that is, the amount marketed, was only 31,793,027 tons, worth $71,534,311.
c Year ending May 31.

RÉSUMÉ OF THE VALUES OF THE METALLIC AND NON-METALLIC MINERAL SUBSTANCES PRODUCED IN THE UNITED STATES IN 1883.

Metals.....	$203,116,859
Mineral substances named in the foregoing table.....	241,087,769
	444,204,628
Estimated value of mineral products unspecified.....	8,000,000
Grand total.....	$452,204,628

METALLIC PRODUCTS OF THE UNITED STATES IN 1882.

	Quantity.	Value.
Pig iron, long tons, spot value.....	4,623,323	$106,336,429
Silver, troy ounces, coining value.....	36,197,695	46,800,000
Gold, troy ounces, coining value.....	1,572,186	32,500,000
Copper, pounds, value at New York City (*a*).....	91,646,232	16,038,091
Lead, short tons, value at New York City.....	132,890	12,624,550
Zinc, short tons, value at New York City.....	33,765	3,646,620
Quicksilver, flasks, value at San Francisco.....	52,732	1,487,042
Nickel, pounds, value at Philadelphia (*b*).....	281,616	309,777
Antimony, short tons, value at San Francisco.....	60	12,000
Platinum, troy ounces, value, crude, at New York City.	200	600
Total.....	....	$219,755,109

a Including copper made from imported pyrites.
b Including nickel in copper-nickel alloy.

NON-METALLIC MINERAL PRODUCTS OF THE UNITED STATES IN 1882 (SPOT VALUES).

	Quantity.	Value.
Bituminous coal, brown coal, lignite, and anthracite mined elsewhere than in Pennsylvania....long tons (*a*)	60,861,190	$76,076,487
Pennsylvania anthracite.....long tons (*b*)	31,358,264	70,556,094
Crude petroleum.....barrels (*c*)	30,053,500	23,704,698
Lime.....barrels	31,000,000	21,700,000
Building stone.....	....	21,000,000
Salt.....barrels	6,412,373	4,340,140
Cement..... do.	3,250,000	3,672,750
Limestone for iron flux.....long tons	3,850,000	2,310,000
South Carolina phosphate rock.....long tons (*d*)	332,077	1,992,462
New Jersey marls.....short tons	1,080,000	540,000
Concentrated borax.....pounds	4,236,291	338,903
Mica ..... do.	100,000	250,000
Natural gas.....	....	215,000
Ocher .....long tons	7,000	105,000
Soapstone.....short tons	6,000	90,000
Crude barytes.....long tons	20,000	80 000
Precious stones.....	....	75,000
Gold quartz souvenirs, jewelry, etc.....	....	75.000
Pyrites.....long tons	12,000	72,000
Manganese ore..... do.	3,500	52,500
Chrome iron ore..... do.	2,500	50 000
Asbestos.....short tons	1,200	36,000
Graphite.....pounds	425,000	34,000
Cobalt oxide..... do.	11,653	32,046
Slate ground as a pigment.....long tons	2,000	24,000
Sulphur.....short tons	600	21,000
Asphaltum..... do.	3,000	10,500
Corundum..... do.	500	6,250
Pumice-stone..... do.	70	1,750
Total.....	....	$227,461,580

a The commercial product, that is, the amount marketed, was only 57,963,038 tons, worth $72,453,797.
b The commercial product, that is, the amount marketed, was only 29,120,096 tons, worth $65,520,216.
c Pennsylvania and New York field only; the outside production was very small.
d Year ending May 31.

RÉSUMÉ OF THE VALUES OF THE METALLIC AND NON-METALLIC MINERAL SUBSTANCES PRODUCED IN THE UNITED STATES IN 1882.

Metals.....	$219,755,109
Mineral substances named in the foregoing table.....	227,461,580
	447,216,689
Estimated value of mineral products unspecified.....	8,000,000
Grand total.....	$455,216,689

This total for 1882 has been increased, by corrections and additions, $1,304,283 upon the figure given in the first report of this series, which was $453,912,406.

TECHNICAL EDUCATION—SIBLEY COLLEGE.

SIBLEY COLLEGE is the School of Mechanical Engineering, and of Mechanic Arts, of Cornell University. It has a complete organization, separate buildings, containing lecture-rooms, drawing rooms, museums of collections of machines and apparatus, and workshops, in which instruction is given in the working of wood and of the metals. It is organized as follows:

At the head of the college is a presiding officer, called the "Director," who, by direction and authority of the Trustees, will plan the several courses of instruction, and determine upon the best methods of tuition in the several departments of the college, and who will see the whole system of instruction kept in operation, in accordance with the plans laid out by him, and approved by the authorities of the University. He is made responsible for the efficiency of the material and personnel of the college, for its proper organization and administration, and for its operation in accordance with the policy and general methods of the University. In all such matters, and in those in which the college is brought into contact with the workings of the University, and the departments exterior to itself, a special Faculty is consulted, as an advisory body, and the general Faculty is expected to assist in effecting all arrangements by which the co-operation of such departments is to be secured.

The college is divided into three principal departments, each of which is presided over by a professor skilled in the subject, instruction in which is directly conducted by him and his assistants. These departments are "Mechanical Engineering," including a Mechanical Laboratory, in which experimental work and investigations are conducted; a department of "Practical Mechanics," or shopwork, and the department of "Drawing and Machine Design." The first named is presided over by the Director, who is also the Professor of Mechanical Engineering. The two other departments will be directly managed by professors conversant with the special work falling within their lines. Assistants and skilled workmen are employed in these several departments as needed.

When fully organized and in operation as intended, the course of instruction in Sibley College will, as a rule, be arranged with reference to the demands of students desiring ultimately to take the degree of "Mechanical Engineer." The lecture-room course of instruction consists of the study, by text-book and lecture, of the materials used in mechanical engineering—especially of steel and iron—the valuable qualities of these materials being exhibited in the mechanical laboratory, by the use of the various kinds of testing machines, as well as by examination of specimens of all the most familiar grades, of which samples are seen in the cases of the museums and lecture-rooms. The theory of strength of materials is here applied, and the effects of modifying conditions, such as variation of temperature, frequency and period of strain, method of application of stress are illustrated. This course or study is followed, or accompanied by instruction in the science of pure mechanism, or kinematics, which traces motions of connected parts, without reference to the causes of such motion, or the work done, or the energy transmitted. This study is conducted largely in the drawing-rooms, where the successive positions of moving parts can be laid down on paper. It is illustrated, in some directions, by the set of kinematic models, known as the Reuleaux model, the only complete collection of which, in the United States, is found in the museums of Sibley College.

The study of Machine Design properly succeeds that of pure mechanism, just described, and includes the determination of the general dimensions, and of the forms and proportions of the principal parts of machinery, both as fixed by the strength of material and form of the members designed, and by the method of connection to adjacent parts of the construction. This study also is largely conducted in the drawing rooms, and is

directed by an instructor familiar, practically as well as theoretically, with the designing and proportioning of machinery. The study of mathematical principles, and of the strength of materials as applied in this portion of the work, is pursued at an earlier period of the course of preparation for these professional studies, in the several other departments of the University to which such preparatory work properly belongs.

The closing work of the course consists in the study, by text-book and lecture, of the theory of the steam-engines and other motors, including both the mechanical and the thermodynamic principles, and an examination of the structure of that class of machinery; this course of instruction being followed, as far as may be found practicable, by exercises in designing and proportioning such engines. The last term of the regular four-years' course is devoted, mainly, to the preparation of a graduating thesis, in which the student is expected to exhibit something of the working power and the knowledge gained during his course. This thesis may be either a treatise upon some subject having professional interest, and which has not been hitherto fully treated, or an account of some new and useful form of machine devised by the writer, and of which he will present the theory and method of design; or it may be an account of some original design of works fitted for manufacturing specified products, or an investigation having direct and practical bearing upon problems of importance arising in the course of professional work. Of these several kinds of thesis, the last two named are given, as a rule, highest value. The thesis is rejected, and the student is not given his diploma, should his production not give evidence of originality and strength, and of having profited, to a very creditable extent, by the opportunities which have been offered him.

The general course is accompanied by systematic instruction, as already stated, in the drawing rooms and in the workshops.

The course of instruction in mechanical drawing is progressive, from geometrical drawing to the designing of machinery and the making of working drawings. The aim is to familiarize the student with methods adopted in the best drawing offices. Working drawings and blue prints have been obtained from our most prominent engine and machine builders, whose practice is thus shown in the clearest possible way. A large collection, containing several hundred drawings, selected from the best technical schools abroad, also aids in this work.

The aim of the instruction in shop-work is to make the student, as far as time will permit, acquainted with the most approved methods for the construction and inspection of machinery. Every student is required to devote nine hours per week to work in the shops, or about thirty days during each year.

This course begins with a series of exercises in wood-working, each of which is intended to give the student familiarity with a certain application of a certain tool, and the course of exercises, as a whole, is expected to enable the industrious, conscientious, and painstaking student to easily and exactly perform any ordinary operation familiar to the carpenter, the joiner and the pattern-maker. Time permitting, these prescribed exercises are followed by practice in making members of structures, joints, and of small complete structures, and of patterns, their core boxes, and other constructions in wood.

The wood-working and pattern shop is thoroughly equipped for teaching the use of all ordinary tools and machines for working wood. Particular attention will be paid to the details of pattern making.

This course is expected not only to give the student a knowledge of the methods of the carpenter and the pattern maker, but to teach him how to handle tools, and to give him that manual skill in the handling of machines which will permit him to enter the machine shop, and there to quickly acquire familiarity and skill in the manipulation of the metals, and in the management of both hand and machine tools, as used in the working of such metals.

The instruction in the machine shop, in the foundry, and the blacksmith shop is intended to be carried on in substantially the same manner as in the wood-working course, beginning by a series of graded exercises, which will give the student familiarity with the tools of the craft and

with the operations for the performance of which they are particularly designed, and concluding by practice in the construction of parts of machinery, and, time permitting, in the building of complete machines which may have a market value. The time allowed for work in the shop is not, and cannot well be, sufficient to teach the student all the methods of the several trades, or to make him, unless an exceptionally good mechanic by nature, a skilled workman; but it is hoped that the amount of time given to shop work may be hereafter somewhat enlarged, and that the course may be gradually extended in length, and given increased efficiency in method. With the time now given, however, the instruction in this, the department of the mechanic arts, is found to be of very great value to the student.

The mechanical laboratory will be devoted to making tests and experiments. The apparatus will consist of experimental engines and boilers, machines for testing the strength of materials, friction and lubricants, and of friction and transmitting dynamometers, etc., etc.

The work in this department will be conducted by an instructor familiar with its apparatus and with the best methods of work, and who will plan a systematic course of instruction which is intended to give the student not only skill in the use of apparatus of exact measurement, but to teach him also the best methods of research, and to give him a good idea of the most effective methods of planning and of prosecuting investigations, with a view to securing fruitfulness of result with minimum expenditure of time and money. In this, as in every other department, the instructors are expected to keep in view the more important methods of practical work coming to the engineer in his daily practice. The object of all the theoretical instruction is to give the student power to solve the problems arising in every-day life, and to make him familiar with the best methods of uniting theory and practice in such manner as to enable him to reach a defined object most directly, and with greatest certainty.

The professional work of the college is based upon courses of preparatory study, which include the usual branches as taught in the high schools and colleges of the country, and exceptionally extended and thorough courses of instruction in mathematics and in the physical sciences. These preparatory studies are pursued in the various appropriate departments of the University, as described in the "Register," and instruction is facilitated by the use of a very extensive collection of apparatus, illustrating the facts and principles presented to the students by the lecturers in each department in which such apparatus can be so used.

Students who have completed the course of study above outlined, who have the time and means, and who desire advanced instruction in either of several lines of mechanical engineering, after graduation, may continue their studies through a fifth year, taking up the courses prescribed in the register, and a certain number of optional studies, which are selected with a view to making the year as profitable, professionally, as possible. The courses now ready are those in Marine Engineering and Naval Architecture, in Steam Engineering, in the Mechanical Engineering of Railroads, and in special laboratory investigation. Should the student desire to pursue his studies still further, he may do so as a resident graduate, taking such lines of reading and of experimental investigation as he may consider best, still subject, however, to the approval and supervision of the Director and of the head of the department in which his work may be carried on. The details of all courses of instruction, and of all lecture courses open to the student, whether graduate or undergraduate, are described in the Register of the University, which is mailed to all applicants by the Treasurer. It will be seen that laboratory practice in chemistry and physics, which is invariably found to have peculiar value to the mechanical engineer, forms a very important and extended part of the scientific instruction assigned to the student in every department of professional work in engineering.

Sibley College was founded as a college of the Mechanic Arts, and is intended by the Trustees of the University to be made not only a school of arts and trades, but a college of engineering, in which schools of the mechanic arts, and of the various branches of mechanical engineering, shall

be developed, as rapidly and as extensively, as the means placed at the disposal of the Trustees of the University, and a demand for advanced and complete courses of instruction, shall allow. The courses now ready will be supplemented by other and more advanced courses, from time to time, as the number of students applying for advanced instruction shall justify further exp ansion; and it is hoped and anticipated that, in time, the college may embrace schools of every branch of mechanic arts, and of mechanical engineering, which may assume prominence in connection with the development of the great industries of the country. Its buildings and equipments are already extensive and remarkably well adapted to the work to be done.

The buildings of Sibley College have been erected and presented to the University by the Hon. Hiram Sibley, of Rochester, N. Y., to whose intelligent and patriotic liberality the University is also indebted for the workshops, tools, and nearly all of the illustrative appar atus. The Sibley professorship of Practical Mechanics and Machine Construction is sustained by an endowment, which is another of the gifts of the same friend of the University.

The main building of Sibley College is constructed of stone, and is 160 feet in length and 40 in breadth, and three stories in height. It contains the lecture-rooms, drawing-rooms, and museums of the college, and is connected with a series of workshops, including a wood shop, machine shop, forge, foundry, and mechanical laboratory, with rooms devoted to various other purposes, and with the janitor's house.

The wood-working shop is supplied with all needed hand and power tools, work-benches, and accessories sufficient for sections of classes up to twenty-five or more in number, should it be found advisable to work so many together.

The machine shop is supplied with lathes of various kinds, planers, grinding, drilling, and shaping machines, a universal milling machine fitted for cutting plane, bevel and spiral gears, spiral cutters, and twist drills, with additional tools and attachments for graduating scales and circles and for working various forms and shapes.

In addition to the usual hand and lathe tools, there are instruments of the greatest accuracy consisting of standard surface-plates, straight-edges, and squares of various sizes; a standard measuring machine reading to the ten-thousandth of an inch, a universal grinding machine for producing true cylindrical and conical forms, and a set of Betts' standard gauges.

The smithy contains ten forges of the most approved pattern, and corresponding outfits of smiths' tools. The instruction embraces forging, welding, tempering, etc.

The foundry is equipped for giving thorough instruction in loam and sand moulding, and the casting of iron and brass. The cupola for melting iron is a Colliau's improved, with a capacity of one ton per hour. There are also a crucible furnace for melting brass, a core oven, a rattler, and the other usual foundry appliances.

The mechanical laboratory is supplied with several kinds of testing machines, including those made by Fairbanks & Co., for tests of beams; by Riehle Brothers, for rapid work in tests by tension; by Olsen & Co.. for slower, but more precise, work in determining, especially, the elastic properties, and the modulus of elasticity of materials; and by the Pratt & Whitney Co., the latter being an "Autographic Recording Testing Machine," used in making special investigations of the properties of the materials used in construction. A Brown and Sharpe machine, for testing the strength and ductility of fibrous materials, completes the list of testing machines. Other machines are used, in the course of laboratory instruction, for determining the value of lubricants, their endurance under work, and their coefficients of friction. Dynamometers will be brought into use in measuring the power of prime-movers, and the work done in driving machinery. Steam-engine indicators, of which all the most familiar kinds are represented in the collections, are applied to testing steam-engines, and other heat motors; and steam gauges, counters, and other minor kinds of testing apparatus, and instruments of exact measurement, are made, in various ways, to illustrate the course of instruction in this line of work. The test trials of steam-boilers, and the testing of other

apparatus and machines, to determine their capacity, efficiency, and adaptation to their intended purposes of application, form part of this course, and the needed apparatus is provided here as required. The collection of mechanical laboratory apparatus in these departments is already exceptionally rich and complete, and is expected to be steadily increased by annual accessions by purchase and gift from members of the profession and others interested in this branch of technical education.

The museums of Sibley College contain the Reuleaux collection, illustrating the course of instruction in mechanism; a very interesting collection of other apparatus having a similar use; various forms of steam-engine governors; models illustrating the forms of parts of machines, and of complete constructions; a large variety of machinery, such as is seen in the market, contributed, in most cases, by the makers; and many objects which cannot be so well classified, which are, however, all of interest to the student of machinery. The drawing rooms are carefully fitted up with a view to convenience and efficiency of work in instruction, and are supplied with all the instruments, models, casts, and other material needed. Students are also expected to make free use of the collections in the museums, and to sketch in the workshops, as they acquire expertness in the handling of instruments, and power in the use of the hand. The lecture rooms are fitted up, each with a view to the work to be done, and contain cases of apparatus and models, drawings, wall charts, and samples of materials in use in the arts and trades, all so arranged that the instructor may bring them before the class with least possible loss of time, or expenditure of labor.

A lyceum is also fitted up, for the use of students who are enrolled in the association to which it is assigned, in which weekly debates are carried on, and in which the working library of the department may be gathered.

Supplementing the regular course of instruction, a series of lectures will be delivered in the lyceum and in lecture rooms, irom time to time, by members of a body of "Non-Resident Lecturers," who have been chosen from among the most distinguished men of the profession. These gentlemen choose their own subjects, and times of lectures, and their own method of presentation of the subject selected. They will, in some cases, deliver formal lectures, in others open the regular debates in the lyceum, in others give interesting talks to the classes in the lecture rooms, in connection with the work which may be then in hand. In the debates, in which the students are expected to take part freely, the discussion will take such direction as those present may find most attractive and profitable. The formal lectures may, or may not, be followed by debate, as may, at the time seem, in the opinion of the lecturer and of the director, best.

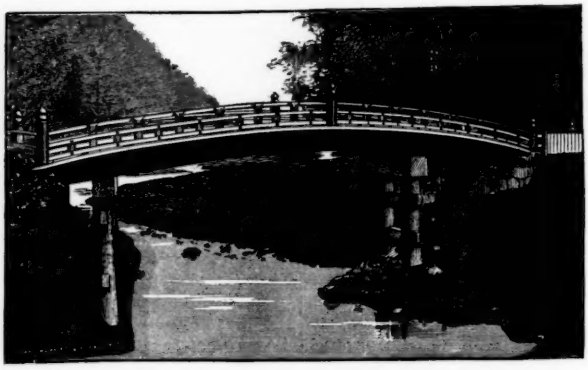
The preceding account of Sibley College represents the present condition of the institution, and the form of its courses of instruction, and indicates what is the intent of the Trustees and of the officers of the University, and of Sibley College, in regard to its position and development. As experience may yield suggestions, and may throw more light upon the possible future of the college, the plans here outlined will be subject to modification, and, it is hoped, to continuous improvement. The announcement here made is, to that extent, provisional. It is, however, the full intention of the Trustees to endeavor to carry out the desires of the Founder, and the policy of the University, as defined by its charter, in such manner as shall secure to students entering this institution opportunities of study, and of acquiring a knowledge of the facts and principles, and of the practice, of mechanical engineering, in whatever branch they may desire to work, such as can nowhere else be excelled, and to promote the growth of the schools of engineering and mechanic arts constantly, rapidly, and healthfully, so as to secure, in their operation, an efficient means of promoting every great industry of the country, while giving to every citizen the means of educating his children in the most useful and desirable directions.

The Director of Silby College is Professor Robert H. Thurston, late of Stevens Institute of Technology.

AN ORIENTAL CANTILEVER BRIDGE.

A LETTER from Yokohama, Japan, bearing date October 6th, gives the following description of an old bridge constructed by native engineers. The cut herewith presented was prepared from a photograph enclosed in the letter.

The writer evidently shared the popular but erroneous impression that engineers had urged the claim of novelty in the cantilever principle.



The following is the description *verbatim*:

"At the Sacred City of Nikko, the other day, I was rather amused and interested at seeing a fine and very costly bridge of cantilever construction—abutments of hewn stone, shore piers hewn granite, octagonal, monolithic, mortised for stone girders; monolithic plate beam to receive wooden superstructure. The stringers are fastened into the abutments, balance over the stone beam, but do not reach, by considerable distance, the gap being fitted by middle stringers let into the shore stringers.

"The Niagara Bridge is a mere amplification of this one, built before America was settled, as a religious duty, very expensive, of thick, red lacquered work, and, like a bridge of angels, its planks are never profaned by the feet of the laity. But it seems queer-like, to come away here to find our new inventions very old."

FARADAY is said to have estimated that there was no more electrical work in a lightning flash than would decompose a drop of water. It must take much more electricity, if this is true, to decompose a drop of water than to do a vastly heavier amount of work. Mr. W. Bellasis writes from Roehampton, August 30: "In case it has escaped notice, an opportunity now offers of witnessing in Richmond Park a truly awful spectacle. On the 6th a storm, scarcely observed elsewhere, burst upon the park. There was but one flash of lightning, which, singling out two fine oak trees, completely destroyed the top portion of one and shattered to pieces the solid base of the other, depositing the immense upper part, neatly severed and intact, some feet away. The explosion must have been terrific, as trees close by are damaged by the large splinters which, dried up and sapless, lie about in all directions."

PHYSIOGRAPHY.

By JOHN EVANS, Assoc. Inst. C. E.

A Lecture delivered before the Institution of Civil Engineers.

The Council of the Institution of Civil Engineers having determined on the delivery of a course of lectures on the Theory and Practice of Hydromechanics have done me the honor of requesting me to give the first of these lectures, and have suggested "Physiography" as my subject. At the time that I expressed my willingness to comply with this request, I hoped that I should be able to find sufficient spare hours to do some justice to the subject, but, unfortunately, owing to the absence of the President of the Royal Society, unexpected duties have devolved upon me, and the small modicum of leisure which my ordinary avocations allow me has been considerably cut down. I must, therefore, beg for some indulgence if in the following remarks I seem to treat my subject in an inadequate manner, and do not in some respects enter into the amount of detail which might not unreasonably have been expected.

But what is my subject? The word "Physiography"—for which as a title to my lecture I must deny all personal responsibility—is one of very wide import, and has been defined in the dictionaries as meaning "a description of nature, or the science of natural objects." I shall not attempt to accept the word in this wide sense, or the limits of one, or even of a dozen lectures, would not suffice for the treatment of the subject. And, moreover, it has already been admirably worked out by Professor Huxley in his course of lectures at the London Institution, which have been expanded into a most instructive volume, with the title "Physiography," a work which I have found of some service in preparing for this evening. What I hope to do, is to bring before you such portions only of this great subject as bear more especially on the supply of that indispensable necessary of life with which in various ways the lecturers who follow after me will have to deal, and I must, moreover, limit myself, as far as possible, to the phases of nature which may be observed in our own country.

The water which we consume for our daily use is usually derived from one of three sources—springs,—streams, rivers or lakes,—or reservoirs of some kind in which the rainfall is artificially stored. In all cases, however, the water comes to us more or less immediately from the clouds, and they in turn are fed by evaporation from different parts of the surface of the globe. The principal source whence the air derives its moisture is no doubt the ocean, from and toward which there is a constant circulation of water. As was said by the wise man of old:* "All the rivers run into the sea, yet the sea is not full; unto the place from whence the rivers come, thither they return again."

The air, then, is the great conductor of moisture from the sea and other sources to the springs and streamlets which feed the rivers, and the term "atmosphere"—the sphere of vapor—fittingly describes under one of its most beneficent functions the attenuated fluid which envelops our globe. I need hardly enter into the chemical nature of water, which consists of oxygen and hydrogen in the proportion of one to two, nor into that of air, which is, in fact, a mixture of about one part of oxygen-gas, with about four of nitrogen. To speak accurately, if we take 100 cubic feet of pure air, they will consist of 20.9 feet oxygen and 79.1 feet of nitrogen. If, on the other hand, we take 100 lbs. of pure air, it will be found that they consist of about 23 lbs. of oxygen and 77 lbs. of nitrogen. Air, however, as a rule, is not absolutely pure, but usually contains about four parts in the one thousand of carbonic-acid gas, as well as smaller proportions of ammonia, hydrogen and nitric acid. These may all have some slight effect on water falling through the air, but in considering the air as an absorbent of aqueous vapor, the minor constituents may be entirely disregarded. Practically, the air is never free from this aqueous vapor, for, how-

* Ecclesiastes i. 7.

ever dry it may appear, yet, when tested by powerful absorbents of moisture. water is constantly found present. The hotter the air the more capable it is of absorbing moisture and holding it in invisible suspension, we might almost say in solution. On the coldest day, however, the air retains some power of absorbing moisture, and will even carry it off from snow or from a lump of ice. As water itself, under ordinary circumstances, is converted into steam at a temperature of about 212° Fahrenheit, it is evident that with air at this or a higher temperature an invisible admixture of air and water might exist in almost any proportions. For it must be borne in mind that the ordinary conception of steam being visible is entirely erroneous. It is not until it has to some extent been condensed and reduced into small particles of water that steam assumes a visible consistence. If, on a bright day, we watch the steam blowing off from the safety-valve of a locomotive engine, we can observe three phases. Close to the valve there is little or no appearance of vapor, next we can observe volumes, in fact clouds, of visible steam being gradually formed, and as these are wafted away in feathery streaks by the wind they gradually disappear, the vapor having been absorbed and incorporated in the air, to be again deposited in the form of a visible cloud and eventually of rain at some future and possibly long distant time.

The quantity of moisture present in the air varies considerably in different countries and at different seasons. Here, in England, it is said that the average proportion of water present in the air is about 1½ per cent. When the air at an ordinary temperature is nearly saturated, a slight reduction of heat suffices to make the moisture visible. How often do we not observe a mist rising, as it is called, towards sunset, after a bright warm day; and how often have we not seen the morning's mist, and even the clouds at a higher level, gradually disappear under the genial influence of the sun's rays.

The power of the air to carry off vapor has been put to the test by various experimental researches. In our own country, Howard, at Plaistow; Greaves, at Lea Bridge; Laws and Gilbert, at Rothamstead, and others, have investigated the subject. From shallow vessels at Plaistow, and from a larger surface of water at Lea Bridge, the annual evaporation was about 21 inches per annum, and, as might be expected, the quantity varied at different seasons of the year. Speaking roughly, it was about as follows:—January to March, 4 inches; April to May, 8 inches; June to September, 7 inches; October to December, 2 inches. At Dijon, about 26 inches were carried off from the surface of large vessels of water. Extensive observations made in Denmark show about 28 inches from water, 30 inches from short grass, and 44 inches from long grass.

In hotter regions the evaporation must be greater still; and I may just refer to the Dead Sea, into which the river Jordan is constantly flowing, and which, notwithstanding, is kept by evaporation at a level of more than 1,300 feet below that of the Mediterranean. Even the Mediterranean itself affords another instance of the wonderful power of the sun; for, notwithstanding the volume of water poured into it and the inland seas connected with it by the large rivers, such as the Rhone, the Po, the Danube, the Dnieper, the Don, and the Nile, this accession to its waters appears to be insufficient to keep pace with the evaporation from its surface, as notwithstanding occasional outward undercurrents, there is almost constant inset of the current through the Straits of Gibraltar. At Madras, it has been found that there is an annual evaporation of about 90 inches; and from a reservoir at Nagpoor, evaporation went on at the rate of one-fifth of an inch per diem, so that 48 inches disappeared in the course of two hundred and forty days. At Dublin, on the average of two years, Dr. Haughton found that the evaporation fell short of the rainfall by only 1 inch. In fact, Mr. R. H. Scott thinks that in nearly all parts of the globe, the evaporation from a free water surface is on the average about equal to the rainfall. The effect of wind is largely to increase the evaporation, and the hot winds of the equatorial regions, acting on the surface of a warm sea, become highly charged with vapor. It is, indeed, mainly from the surface of the ocean that the supply of aqueous vapor in the atmosphere must be derived. The fine warm weather which dries up a land surface un-

til but little moisture is left to evaporate, makes the air which is brought in contact with the waves of the sea all the more avid to receive water, of which it then finds no stint. How readily the air parts with some of the moisture suspended in it, when brought in contact with a cold surface, is well shown by the hackneyed example of a glass of cold water brought into a warm room. The effect of currents of colder air meeting warmer currents fairly charged with moisture is first evinced by the condensation of minute particles of water, which, though still in suspension in the atmosphere are visible in the form of cloud, mist or fog. A greater or more continued chill causes these particles to increase in size, coalesce, and descend as rain, hail or snow.

In falling from the clouds, rain increases in quantity as it descends, probably by the absorption of vapor, or of minute particles of water in the state of mist. Experiments have shown that this increase is very marked. Even at 3 feet from the ground there is said to be two per cent. less of rain than at the surface; at 20 feet, twelve per cent.; and at 50 feet, twenty-three per cent. It is, nevertheless, somewhat doubtful whether this law of increase universally holds good. While, however, in an open plain there is less rain at a considerable height above the ground than at the surface, somewhat different conditions prevail in mountainous districts, for the actual amount of rainfall increases as a rule as we ascend the slope of a mountain. Mountain ranges, indeed, are the great condensers of atmospheric moisture, and the amount of rainfall of any country is in the main dependent on the position of these ranges, and the prevailing direction of the winds.

India affords a good example of this fact, as the trade-winds, or "monsoons," as they are there called, exhibit great regularity in their occurrence. From the end of October to the end of April there is little or no rain on the western coast, but during the other six months, after the monsoons have set in, rain falls in abundance. At Bombay, near the sea-level, the most rainy months are those of June and July, during which from 40 to 50 inches annually fall. During the whole of the rainy season the average of seven stations at the sea-level in the Bombay Presidency is about 80 inches. At an elevation of about 900 feet in the Southern Concan Hills or Western Ghâts there is an increase to about 135 inches, and at Mahabuleshwur, at a height of 4,500 feet, and at a distance of 130 miles from the sea, the annual fall is over 250 inches. It is rarely that the hot stratum of aqueous vapor brought from the equator by the south-west monsoon floats at a higher level than this. In dashing against the precipitous western face of the Ghats much of the warm stratum is thrown up among the colder layers of air at higher levels; but a little is carried eastward to be condensed by the Himalayas. So effectually does this high range do its work that the great plain of Tibet to the east may be regarded as rainless. In the same manner while the great central plains of Spain, at an elevation of 1,200 feet or more above the sea, are during the summer months pinched with drought, the seaward face of the mountains that skirt the Bay of Biscay are clothed with verdure and rarely in want of rain.

Great as are the variations in the rainfall in India, they may be equaled, if not exceeded, by those in the British Isles. With us the Gulf Stream with its warm current seems to play an important part in supplying vapor to the atmosphere, and in charging our southern winds with moisture. A glance at a Hyetographical or Rainfall map, such as that prepared by Mr. G. J. Symons, of which he has kindly lent a copy, will at once show how disproportionate is the amount of rain which falls on the western and southern shores of England as compared with that on the eastern. Along our western shores the usual fall is from 40 to 50 inches, and in many districts from 50 to 75 inches; that of the southern coast is from 30 to 40 inches; while in the eastern counties it is less than 25 inches. In some exceptional positions, such as Seathwaite in Cumberland, the average rainfall is upwards of 140 inches. In others, such as Hunstanton, in Norfolk, and some parts of Lincolnshire, it is little more than 20 inches; so that, in effect, there is on an average seven times as much rain in one part of England as there is in another. I am here speaking of an average of about twenty years, but in most places the annual variation is very great, the maximum an-

nual fall being very much in excess of the minimum. Taking, for instance, the rainfall of 1852, and comparing it with that of 1854, I find that in Hertfordshire we we had in the former year rather more than 41 inches, and in the latter a little under 19 inches, or less than one-half; the average of forty years being about 27 inches. Of course, in estimating the water supply of any district, it is the minimum rainfall on which the engineer must base his calculations, and not the average.

Mr. G. J. Symons has carefully considered the limits of fluctuation in the total rainfall, and has arrived at the following conclusions, basing them upon the observations of a long series of years. In any part of this country:

1. The wettest year will have a rainfall of nearly half as much again as the mean.
2. The driest year will have one-third less than the mean.
3. The driest two consecutive years will each have one-quarter less than the mean.
4. The driest three consecutive years will each have one-fifth less than the mean.

At places, however, where the average rainfall is large, the extremes both of wetness and of dryness will be less pronounced than at those where the usual rainfall is small.

I have already mentioned the gradual increase of the rainfall in India as the slope of a mountain is ascended. It has, however, been assumed that, though in this country there is a gradual increase up to about 1,500 feet, yet, that above such an elevation it decreases. It has, indeed, been calculated that one-half of the vapor in the atmosphere is contained in the lowest 6,000 feet, and that at a height of 20,000 feet, there is only one-tenth of the moisture that there is near the surface of the earth, so that, at extreme elevations, there must be a diminution in the rainfall. Dr. Hann has well pointed out, "There must, on high mountains, be an upper limit of the maximum amount of rain. The decrease of temperature with increasing elevation involves a decrease in the amount of vapor held in the air. The maximum rainfall is, therefore, to be expected at the height at which, as a rule, condensation is first produced." As the usual height of *nimbi*, or rain-clouds, is in these latitudes not more than 1,500 feet, and as some of the observations in the Lake District seem to show a decrease above that level, the assumption just mentioned has been commonly accepted as true. Recent observations, however, in the Mountain Observatory on the summit of Ben Nevis, at an elevation of 4,406 feet, compared with those taken near the sea-level at Fort William, at the foot of the mountain, and at the lake, which is at a height of 1,840 feet above the sea, show that while at the lake the increase of the rainfall is about 30 per cent., it is at the summit fully 100 per cent.; in other words, twice as much rain falls on the top of Ben Nevis as at Fort William at the base of the mountain. It is, however, right to say that the observations on which this calculation is based extend over two seasons only, viz., the five months from June to October inclusive, in the years 1882 and 1883. During the other seven months of the year, so much snow falls at the top of the mountain, that exact measurement is impossible.

Our rivers and springs in this country are, as a rule, so little dependent upon the melting during the summer, of the snow that falls during the winter, that I need hardly do more than allude to the glaciers, which, in the case of many continental rivers, are during the summer months their main source of supply. With us, however, the rapid melting of snow is a frequent and principal cause of floods, especially in the case of districts consisting of porous soil, the surface of which has been hard-frozen before the snow fell upon it. Under ordinary circumstances, the gradual melting of snow makes it play much the same part as an equivalent amount of rain. At a rough estimate 12 inches, or 1 foot, of undrifted snow may be taken as an equal to 1 inch of rain.

Let us now consider what becomes of the rain, hail or snow after it falls upon the surface of the earth. With regard to the two latter forms in which water descends from the clouds, we may leave them as they lie, inasmuch as until they assume a liquid form they remain upon the surface of the ground and do not add to the water-supply, being, however, still liable to diminution from evaporation. As the rain, however, or the liquefied

snow or hail, the future course which, under different conditions, it may have to follow, cannot at once be predicated. Although the utmost it can achieve is to remain undiminished in quantity, the falling rain in many respects resembles the good seed in the parable, though that which falls in stony places is, perhaps, that which produces the most abundant results. The amount and quality of the water-supply from a given amount of rain are, in fact, most immediately connected with the geological character of the country in which it happens to fall, through which it passes before being utilized.

If, for instance, we assume a tract of country to exist, consisting of bare, impervious, and unfissured rock, but the surface traversed by valleys all converging to one common outlet, it must be evident that the whole of the rain which falls upon it, less some small quantity carried off by evaporation, will, in a short space of time, be delivered by that outlet. If, instead of a complete valley system, there happen to be some depressed portions forming basins, apart from the valley system, the rain will accumulate in these, and there remain until carried off by evaporation; or, if the rainfall is in excess of the evaporation, the basins will gradually fill, until they arrive at a level at which they can overflow into some part of the valley system. In wet years this overflow may be nearly constant, in average years intermittent, and in dry years it may cease. Assuming again that these basins occupy the half of the area under consideration, it will be seen that while during some portions of a wet year nearly the whole of the rainfall would find its way into the outlet, during a dry year only one half of it would do so, the remainder being retained by the lake basins, and there evaporated.

If, instead of the rock being absolutely bare, there were a certain amount of superficial soil and vegetation upon it, the case would again be altered. Any moderate showers falling upon the area would be absorbed by the soil and the plants upon it, and but little would find its way to the outlet. A few days of fine weather would, in the summer months, when vegetation was in progress, suffice to render the superficial soil again dry and absorbent, so that practically during those months the water passing by the outlet might bear but a small proportion to the rain that fell. In the winter months, on the contrary, the proportion would be inordinately increased, and, even were the rock bare, it would be greater than in the summer, as the loss from surface evaporation would be less. In the case of the rocks being fissured, assuming them to be of an absolutely impervious kind, the result of the existence of fissures, provided they led down to no absorbent stratum, would not materially differ from the results of the presence of lake basins within the area, though the loss from evaporation would be less.

These are, of course, merely assumed cases, intended to show how variable may be the results of the same amount of rainfall under different conditions, although in some of our mountainous districts nearly analogous instances may be found. And it is principally in elevated tracts of country that hard and almost impervious rocks, like granites and gneiss, occur. In such tracts, the rainfall is usually great, and, as the amount lost by evaporation is nearly a constant quantity, the proportion of the rainfall which finds its way into the streams and rivers is large. In the Loch Katrine district, with a rainfall at the head of the loch of 103 inches in 1854, it has been calculated that 82 inches were discharged from the loch, showing a loss from evaporation and other causes of 21 inches.

The outflow from a district formed of heavy clay land will differ from that which results from rain falling on impervious rock, inasmuch as in dry seasons the clay becomes fissured by contraction to a considerable depth, and, though practically impervious, it is by no means unabsorbent. As a rule, too, in this country, such heavy lands are now artificially drained; and tracts of which, in old times, the surface became charged and soddened with water, that either discharged itself gradually, by natural channels, or was evaporated by the sun and wind, have now had their character modified to such an extent, that the rain which falls upon them is absorbed and delivered by the drains into the streams and rivers within a comparatively short time after it has fallen.

In old geological times, floods seem to have played a much more important part than they do at the present day, but they

still cause great difficulties and dangers, with which the engineer has to contend. I need not, however, dwell upon these.

Both in clay districts and those formed of impermeable rocks, it frequently happens that there are superficial patches of drift gravels or sands. These being of an absorbent nature, are, after heavy rains, highly charged with water, some of which is subsequently delivered from them by gravity, at the lowest outfalls, forming what in some districts are called land springs. On permeable rocks, on the contrary, there are occasionally patches of impermeable clay, such as the Tertiary outliers which occur on the chalk; and these being again capped by permeable beds form small water-bearing basins. The position of villages on chalk hills is often due to the circumstance that a supply of surface water is thus made available. Indeed, as a rule, there are hydrogeological reasons for most sites of human occupation.

Although not entering into minute details, Mr. De Rance has given a hydrogeological map of England, which, for the general features of the country is extremely instructive. In it he has divided the character of the soil into four divisions: the impermeable; the partially porous; the "supra-pervious," or clays resting on permeable rocks; and the permeable. In comparing this with the Hyetographical map, it is at once seen how closely the areas of greatest rainfall correspond with those of the impermeable rocks. Nor is this to be wondered at, as these harder rocks have been better able to withstand the wear and tear of rain and rivers and the other denuding forces, and are, therefore, at a higher level and brought into closer contact with the water-yielding clouds than the districts of softer rocks at a lower level. Roughly speaking, the western parts of England and Wales consists of impermeable and partially porous rocks, and the eastern of the "supra-pervious" and the permeable, the area of the latter preponderating. Many of our river basins consist of rocks of two or more of these different kinds, and, in consequence, the flow and the character of the water in the rivers vary much from time to time. In wet weather many are subject to floods, owing to the water from impermeable and "supra-pervious" rocks being delivered into them. At such times their waters will be turbid, and probably contain less matter in solution than during dry weather, when they are mainly fed by springs rising out of the more pervious rocks, such as sandstone, limestone, and chalk.

The areas of the catchment basins of our rivers, and the extent and character of their flow, have of late years all been fairly well determined, and I need not enter into details concerning them. The streams and rivers form, as it were, parts of an extensive superficial drainage system, and the valleys through which they pass, though some are of old geological date, have in the main been excavated by the streams themselves, aided by the action of rain and frost.

To return to the history of the fallen rain. In addition to the supra-pervious beds, of which I must say a few words further on, a very large portion of England—and it is this part of the United Kingdom with which I believe we are here more particularly concerned—consists of more or less absorbent rock underlying a still more absorbent superficial soil, and it is to this fact that the comparatively permanent character of most of our rivers is due. It will be well, therefore, to consider in some detail the history of the rain falling upon such soils, from the time of its fall until it is well on its course to the sea. And for the present it will be best to leave aside any questions as to the proportion of it lost by evaporation and vegetation. Any moderate rain falling on an absorbent soil, whether plowed or covered with grass, at once disappears from the surface, and finds its way among the particles of the soil. In light soils, so universally is this the case, that even in heavy thunderstorms it is of rare occurrence that the water accumulates on the surface in such quantities as to run down the slope of a hill. As a consequence, in districts consisting of such soils, floods are almost unknown, and, when they do occur, are usually due to one of two causes. First, that the ordinary channels of the stream are insufficient to carry off the water delivered into them from the lanes, roads, and roofs of the district in which a heavy storm has fallen, for of course all these are unabsorbent; or, secondly, that the surface of

the soil is hard frozen, and thus, as it were, waterproofed at the time of a heavy fall of rain, or a rapid thaw of snow.

The capacity of some soils or rocks for holding water in the interstices of their substance is great. In the case of the New Red Sandstone of Liverpool, Mr. Isaac Roberts found that it would absorb $\frac{1}{12}$ of its own weight of water, of which about one-half would not drain away, as it was held in the pores of the stone by capillary attraction. In loose sand and chalk, it has been stated that the absorption is from $\frac{1}{10}$ to $\frac{1}{9}$ of the weight, or at the rate of 2 gallons to the cubic foot. In oolites and limestones the proportion is less, but a cubic foot will still absorb from 10 to 14 pints of water. With continued rainfall anything in excess of what can be retained by capillary attraction gradually gravitates downwards until it arrives at a point where the rock is already charged with water. In the bottom of valleys with streams running along them, this saturated rock or soil will be met with near the surface, but the rain falling on hills may descend hundreds of feet before arriving at the point where its further progress is stopped by the spaces in the soil being already occupied with water, and then its effect is to add to the height of the already saturated portion. It will be asked, "What is it that keeps the bottom of the valleys charged with water, and prevents the water under the hills from finding some method of escape?" The answer is, friction. Could friction be removed, the surface of the saturated rock would present a nearly dead level, and the rain would escape at the lowest vent almost as quickly as it penetrated the ground. It is true that in most districts the absorbent rocks, such as sandstone, limestone and chalk, are underlain geologically by non-absorbent beds, such as clay, which prevent the rainfall from percolating to so low a level as that of the sea; but the inclination of the surface of the fully-saturated portion of the rock is quite independent of the underlying beds, and follows much the same laws when the pervious beds extend below the sea-level, and the natural vent for the surplus water is along the line of the sea shore, and not into any streams or rivers. At Brighton, for instance, the surface of the saturated portion of the chalk gradually slopes upwards as it recedes from the sea, this inclination being due to the frictional resistance offered by the pores and crevices in the chalk to its lateral passage. There is, however, a constant or nearly constant outflow from the chalk towards the sea; and though by the action of the tides the level of the outfall varies, the sea is never able to penetrate any distance into the chalk, and the rainfall in each year suffices to keep up an inclination sea-wards in the water-line or the surface of what has been termed the subterranean reservoir in the chalk. We can, however, imagine such a dearth of rain during many successive years that the plane of saturation would be level, or nearly so; and in that case, if by pumping from a deep well an artificial outlet for the subterranean water were formed below the sea-level, the salt water would, by gravity, find its way through the interstices in the chalk, and the water pumped would be brackish, or even salt. The same remarks which apply to springs discharging into the sea, will apply to those which find their outlet along the course of tidal rivers.

Turning now to an inland district, say also in the chalk, such as Hertfordshire, we find that it is intersected by valleys, into the origin of which I need not here enter, and that along the bottom of these there is a constant outpour of water from springs either along the beds of the stream or at their sides. By means of these the volume of the streams keeps gradually increasing as they flow; and, as they are found to be nearly independent of any immediate rainfall, it is evident that they are supplied from underground sources, and, in fact, are draining a subterranean reservoir of water among the crevices and interstices of the chalk. I shall speak of the upper surface of this reservoir as the water line, or as the plane of saturation, though it is not, properly speaking, a plane, but an uneven surface presenting valleys and elevations closely allied to the surface of the ground above it, though, so far as elevations are concerned, much less in degree. The extent to which friction impedes the passage of water through pervious rocks varies considerably even in chalk. It must, however, in all cases, be sufficient to retain the underground water at a slope fully as great as that of the streams

running on the surfaces. In the middle chalk in Hertfordshire this slope is about 12 feet 6 inches to the mile, and near the outcrop in the lower portion of the white chalk, about 19 feet 6 inches. In some parts of Kent it is as much as 40 feet to the mile. It is evident, that could the water find its way along underground, with a less head than, say, 12 feet 6 inches to the mile, it would do so, and the streams would disappear. We can therefore assume that, even in comparatively dry seasons, the plane of saturation may be regarded as presenting much the same contours as the country itself would present were the hills planed away until their slope presented uniform gradients of about 13 feet to the mile. After heavy rainfalls, however, the water descending through the soil and arriving at this plane would gradually be piled up until the slope might be two or three times as much as this 13 feet to the mile; and in dry seasons the water thus piled up would, by the force of gravity, again subside and be delivered into the outlets along the bottoms of the valleys. The spring heads or sources of the streams would, owing to the accumulation of water from heavy rainfalls, be gradually driven higher up towards the heads of the valleys, so that the length of the streams might be increased by some miles. This is no fancied case, for I have known the source of the little river Ver to be at least five miles farther up the valley in one year than in another; and I have known the depth of water in a well at a considerable distance from a stream to vary as much as 70 feet in two consecutive years.

One can indeed imagine such a continued fall of rain that the whole body of the hills would become saturated with water, and the plane of saturation correspond with the configuration of the land surface. In such a case the wells would be full to the brim, as where there is no great draught upon them the level of the water in wells shows the position of the water line or plane of saturation. Where the pumping from a well in a porous rock is excessive, the level of the water in it is reduced below that of this plane, and an inverted cone of depression is formed in the plane of saturation, the angle of which is determined by the amount of friction in the rock.

Of course, the inclination of the plane towards the bottom of the valleys in which the water escapes is constantly varying. If the rainfall which finds its way into the ground is in excess of the water escaping by the springs, the angle of the plane becomes greater. If, on the contrary, the escape by the springs is greater than the absorbed rain, the angle is reduced. It is this circumstance which accounts for the intermittent streams which are commonly known as "bournes." These are usually situated in transverse valleys, running into some main valley in which there is a stream. Assuming that the inclination of such transverse valley is 20 feet to the mile, it is evident that so long as the inclination of the plane of saturation is at a less gradient, no water will be visible above ground; but so soon as the 20 feet is exceeded in consequence of a wet season, the bottom of the valley intersects the plane of saturation, and it becomes the course of a stream which continues to run until the angle of the plane of saturation again becomes less than that of 20 feet to the mile. When the bottom of the valley is uneven, and the slope of the plane of saturation nearly corresponds with the mean of that of the valley, the phenomenon is seen of a watercourse running at intervals along the bottom of the valley, the water finding its way underground where there are prominences in the land surface.

Although the whole of the chalk below the plane of saturation is full of water, and more or less pervious in every direction, yet as the surface of the plane descends, the water, in escaping into the valleys, follows certain lines of least resistance, and thus in many places gives rise to springs sometimes of great volume.

In the upper portion of the chalk there are usually layers of nodules of flint, extending over large areas and occurring at intervals of 3 or 4 feet, the one over the other. Among these flints the underground water seems often to find its way more readily than through the interstices and crevices in the chalk itself; so that, in boring, an accession of water is obtained directly a layer of flint is traversed. So readily do these waterways communicate with the stores of water at a higher level, that the water in a deep boring in the bottom of a valley will rise

higher than the level of the stream running through it, and overflow into its course.

From deep borings the water generally rises at a higher temperature than from ordinary springs. The water from the well-known artesian well at Grenelle, close to Paris, has a temperature of 82° Fahrenheit, and comes from a depth of rather more than 1,800 feet. This temperature is about 30° above that of the springs of the districts, showing an increase of about 1° for every 60 feet of the descent. At the bottom of the deep boring lately made at Richmond, 1,334 feet from the surface, the water has been found to have a temperature of 75½° Fahrenheit, from which an increase in heat of 1° to every 53 feet in depth has been deduced. This increase in temperature in descending from the surface seems universal, though varying in degree in different localities; and it seems probable that in most cases the heat of thermal spings is due to the fact that the channels through which the water has to pass between the time when it is received into the ground at one place, and that at which it reappears at another, descend to a great depth from the surface.

But, to return to the chalk. Where this rock is overlain by stiff clay, through which, however, it in places penetrates, what are known as swallow-holes are formed, and the rain, falling on tracts of impervious clay, forms streams, which find their way to such swallow-holes and disappear in the chalk. In such cases, it seems probable that by the continual delivery of large bodies of water into one place, the lines of least resistance in the chalk have been widened out by combined mechanical and chemical action, so that subterranean watercourses are formed. The caverns, which occur in so many limestone districts, often owe their origin to nearly similar causes.

It not unfrequently happens that pervious strata lie between others of an impervious character, forming, as it were, a porous basin placed between two other basins. In such cases the pervious beds become saturated with water, and the excess of the rainfall finds its way towards the sea over the exposed portion of the beds. A boring made through the upper impervious basin will tap these water-bearing beds, and, if the exposed portion is at a higher level, the water will probably rise to the surface, or even higher, and form a true artesian well. Of course, any water taken from this well will eventually affect the plane of saturation at the exposed portion of the beds, and, assuming that there is no disturbing element, the flow of the streams over them will be diminished to the extent of the water taken from the well. In some cases, the naturally pervious beds beneath the impervious are so much consolidated by their weight, that the free passage of water through them is impeded, and though at first the artesian wells yield an abundant supply, it gradually diminishes, and pumping has to be resorted to, so that eventually a cone of depression is formed around the wells. I need hardly do more than mention the deep wells in the chalk under London as an instance of this phenomenon.

I have hitherto been speaking of the rainfall as if the whole of it that sank below the surface found its way to the saturated portion of the pervious rocks. This, however, is far, very far indeed, from being the case. During the summer months the amount of the rainfall carried off by evaporation, and by the vegetation which is going on all over the surface of the ground, is very large, often fully as great as the rainfall; and even during the winter, unless the rainfall has been continuous, it penetrates but a little way into the ground, and does not get beyond the reach of the evaporating power of the sun and the air. We have only to turn over a few spadefuls of earth to see how small a distance even a heavy shower penetrates a dry soil.

The first to make experiments on the subject of the proportion of percolation through about 3 feet of soil to the rainfall on the surface were Dr. John Dalton, of Manchester, and M. Maurice, of Geneva, about the end of the last century. Since that time numerous experiments have been conducted by various observers, both here and abroad. The principle on which they have been carried on is much the same in all cases. An impervious vessel, open at the top, is sunk in the ground, so that the sides, which are brought to a knife-edge, barely protrude above the surface. It is then filled with soil of the character on which it is pro-

posed to experiment, and the surface is either left bare or clothed with vegetation. From the bottom of the vessel a pipe conveys any water that penetrates so far from the surface into a suitable receiver. This is carefully measured, and its volume compared with that of the rain falling on the surface as ascertained by an ordinary gauge. It has generally been supposed that water which has descended 3 feet from the surface of the ground is beyond the influences of evaporation and vegetation. Capillary attraction seems, however, capable of bringing up water from a greater depth; and the roots of some plants will find their way farther than 3 feet, as will also worms. The difference, however, between the quantity of water which out of a given rainfall descends 3 feet and that which descends 5 feet is not large. The results of many experiments on percolation have been recorded in the Proceedings of this Institution, and those of Mr. Charles Greaves and of Sir J. B. Lawes and Dr. Gilbert are especially worthy of notice. In the latter case the gauges, instead of being artificially filled with soil, were constructed round blocks of the natural soil with a surface area of $\frac{1}{1000}$ part of an acre, and a depth of 20, 40, and 60 inches respectively. The surface of these plots was kept free from vegetation by being occasionally hoed, and the following were the results for the ten years 1871 to 1880. Out of a mean rainfall of 31.451 inches, 14.040 passed through 20 inches of soil, and 13.241 through 60 inches; or, dividing the years into summer and winter periods of April to September, and October to March, it appears that out of 16.365 inches of summer rain only 4.111 found its way through 60 inches of soil, while in the winter there passed 9.130 inches out of a rainfall of 15.086 inches.

I think that I may claim for my uncle, the late Mr. John Dickinson, the honor of being the first in this country to repeat the experiments of Dr. Dalton. His observations began in 1836; but new gauges, formed of cast-iron, were fixed at Nash Mills in 1853, and have been in continuous operation ever since under my own directions. One of the receivers is filled with the surface soil of the district, as nearly as possible as it occurs in nature, and the other with broken chalk, the surface in each case being covered by growing grass. I do not say that the experiments are so fully carried out as those of Mr. Greaves and Dr. Gilbert and Sir J. B. Lawes, inasmuch as the receivers are smaller, and the soil artificially introduced; but they have the merit of being continuous, and in their general results they are corroborated by the observations of others. I have, therefore, arranged the results of thirty years' observations in a diagrammatic form.

The average of the thirty years shows that out of a total rainfall of 27.843 inches, 6 519 passed through 3 feet of soil and 10.650 through the same depth of chalk.

Out of the winter rainfall of 13.752 inches the percolation was 5.707 inches and 8.532 inches; but out of the summer rainfall, when vegetation was in progress and evaporation greater, the amounts are 0.812 and 2.118 respectively out of a rainfall of 14.091 inches. The variations in the proportion of the percolation to the rainfall are very great, even in the winter half-year, so much depending upon the manner in which the rain falls, and whether it is constant for some days or intermittent. I will not detain you with figures, but will give one or two instances of maxima and minima. In the winter of 1879-80 only 5.84 inches of rain fell, of which 2.79 entered the soil to a depth of 3 feet, while in the winter of 1870-1, with a fall of 12.54 inches, only 0.208 percolated.

In the winter of 1882-3, no less than 22.67 inches fell, with a percolation through 3 feet of soil of 11.67 inches, and in that of 1880 81, 13.59 inches percolated out of 20.07 inches. In the summer of 1870 only 7.59 inches fell, and none percolated; whereas, in the summer of 1879, 25.09 inches of rain fell, and 6.94 inches percolated.

With a fall of 11.69 inches in the winter of 1874-5, 4.15 inches percolated; whereas, 9.64 inches in 1858-9 gave only 0.09 inch. In the summer of 1859, 18.09 inches gave no percolation, and in that of 1870, 18.46 inches gave 2.16 inches.

It cannot be too often insisted on that, in the case of water-supply derived from porous soils, it is in the highest degree illusive to depend upon averages. The minimum, or at the best, the lowest average of three successive years, is the utmost on which we can rely. Taking the

triennial period 1862-4, we find that, with a rainfall of about 22 inches, only 3½ inches percolated to a depth of 3 feet in the soil; and from 1869 to 1871, out of 25 inches, little more than 4 inches. The percolation through chalk is greater, but in the first period mentioned the average in the three years was only 5.20 inches.

Nor can it be too often repeated, that every gallon of water pumped and carried away from an absorbent district is so much abstracted from the flow of the streams of that district. There are, of course, some tracts of country—as for instance, on our own southern coasts—in which there are no surface streams, and the natural vent for the underground water is by springs along the sea-shore; but in inland districts the streams form an exact gauge of the excess of the rainfall over the water carried off by the processes of evaporation and vegetation. The streams being merely the overflows from the subterranean reservoir, it is evident that any artificial diminution of the water in the reservoir must, *pro tanto*, affect the streams; and even in those districts where the discharge is towards the sea, that discharge will be diminished in a similar manner. I have heard people speak of vast and inexhaustible stores of water, which have been laid up in the body of the earth for untold ages, and which have merely to be tapped to meet all the necessities of a crowded population; and I have heard others speak of springs as if there were some spontaneous process in nature by which water was produced in unlimited quantities. But all here will readily acknowledge that the water that is upon the earth beneath, and the water that is under the earth, derives its existence from no other source than from the heaven above.

Mr. J. T. Harrison's scheme for obtaining water by means of tunnels in the chalk of the Thames valley merely means that all the water derived from the tunnels will either be intercepted on its way to the river, or filter into the tunnels from the bed of the river itself. The flow of the Thames below will be diminished by just the same amount of water as that abstracted by means of the tunnels.

I have, however, dwelt almost too long on this part of my subject, and will only add that an annual supply of 4 inches of rain will, from every square mile of country, give a daily quantity of nearly 160,000 gallons of water, which, at the rate of 32 gallons per head per diem, would suffice for a population of five thousand souls. A population of four millions, such as that of the metropolitan area, would, therefore, if supplied from deep wells in the chalk, as some have gravely recommended, absorb the total water-supply of 800 square miles of country, or of an area one quarter larger than the county of Hertford, and the whole of the surface-streams over this large area would in dry years absolutely disappear.

I have already mentioned the fact that in many districts, especially those consisting of calcareous rocks, the underground waters have a tendency to form channels through which they pass, in order, eventually, to appear at the surface in the form of springs. The formation of these channels seems in part due to the power of water to dissolve the lime-stone rock through which it passes. Pure water, indeed, possesses but small solvent powers; but when it is charged with carbonic acid, which rain-water derives both from the atmosphere and from decaying vegetable matter in the soil its powers are largely increased, and, as a consequence, the spring and well water in such districts is largely charged with carbonate of lime. In other districts sulphates and chlorides are often dissolved, sometimes to such an extent as to render the waters medicinal or quite saline in character and unfit for ordinary use. These chemical impurities impart to the water containing them the quality of hardness, which the waters flowing off the surface possess in a far less degree. These latter, however, are liable to hold a larger proportion of organic and vegetable matter either in suspension or in solution, and, on the whole, deep well water is probably the more palatable.

It is hardly within my province to speak about the processes which have been introduced for the artificial softening and purification of water, but I may mention the natural agents which to some extent produce these effects. Where, for instance, a wide and shallow lake intervenes in the course of a river, it will often be found that the water passing out is softer than that which enters the lake, some of the salts of lime which were held

in solution having been deposited or absorbed by the vegetation in the lake. Weeds and fishes, although when dead they are sources of impurity, yet when living are great purifiers of water, as it is on the impurities that they subsist. It would indeed be difficult for animal or vegetable life to be maintained in chemically pure water. The exposure of water to the action of air in its course down a river, especially where there are rapids and falls, has a great effect in the decomposition and removal of nitrogenous impurities. These, however, are subjects which will probably be dealt with by my friend Dr. Pole in the next lecture.

As an introduction to what has to follow, I have attempted to give you some slight outline of the natural laws which regulate the circulation of water from the sea through the air to the earth, until it again returns to the ocean. For details there are numerous authorities which may be consulted, such as the various Reports of the Rivers Pollution Commissioners, Mr. De Rance's "Water Supply of England," Mr. G. J. Symons' publications, and those of Professors Prestwich and Tyndall, Mr. Beardmore, Mr. Bateman, and others.

The principal points which, it appears to me, the engineer should always bear in mind are these:

1. That the higher the level and the nearer the sea, especially on our western coasts, the greater is the rainfall.

2. That in these high districts the rocks are, as a rule, more impermeable than in the low, and the supplies to the streams larger and more immediate.

3. That in the low-lying and eastern districts the rainfall is small, and the rocks for the most part absorbent.

4. That while providing means for receiving and dealing with the maximum amount of supply, reliance can only be placed on the minimum, and not on the average.

5. That though in the case of permeable soils the absolute minimum of percolation may be disregarded, yet that the average of three years seems to show that not more than 4 or 5 inches of the annual rainfall can safely be regarded as available for the supply of both the wells and rivers of the district.

6. That any water abstracted from wells in a permeable district is so much abstracted from the sources of the neighboring streams, though in many cases it can be and is returned to them after use.

In addition, I may venture to suggest that while at no town in this kingdom would there probably be much difficulty in obtaining a supply of practically pure water sufficient for drinking and cooking purposes, there exists no physical necessity for watering the roads or flushing the sewers with water of the same pure quality.

My mission this evening does not, however, extend to questions of water-supply. It has been my task briefly to trace what may be termed the natural history of our springs and rivers, and I must leave the subject of how best to utilize their waters in the competent hands of those who are to follow me in this course of lectures.

THE RESISTANCE OF BUILDING MATERIALS TO FROST.

From "The Builder."

This subject has from time to time engaged the careful attention of scientific men, and amongst others, Brard, Braun, and Tetmajer have published in various Continental journals (as well as in special treatises) the results of their detailed investigations. Brard's test consists in the saturation of the material to be tested with a solution of glauber or other salt of a given strength, and in then permitting the expulsion of the salt by crystallization, it being supposed that the salt would produce an effect similar to that of the congelation of water. Braun institutes a comparison between the strength of extension of the material and the force of the solidifying water, assuming that a material is not capable of resisting frost when the former is less than the latter. Tetmajer employs a number,

expressing the proportion between the resistance to pressure in a dry and in a wet state. In addition to the above, Hempel's test with muriatic acid deserves mention.

In reviewing these processes, Herr A. Blümcke points out in the *Thonindustrie Zeitung* that all of them subject the material to conditions which are not to be found in practice, while their more or less complicated nature forms an obstacle to their adoption. On the other hand. the process of Bauschinger is more practical, consisting in the exposure of the material twenty-five times to frost in the open air, the strength before and after the test serving as a guide to the resisting power. The production, by artificial means, of the needful degree of cold suggests itself, but hitherto this process has only been accomplished by the aid of chemicals, which affect the substances treated in such a way as to prevent the ready appreciation of the effects produced by frost. Hence, a proposal of Hericat de Thury has been carefully studied by Herr Blümcke, with the result of his perfecting the following method:

The stones to be tested are placed, two at a time, in a wire framework suspended from a rod. These are placed in a cylindrical metal vessel, sloped off at the foot in funnel form, and with a cover. This is inclosed in a larger vessel of the same shape, and held in position by supports. There is a space of 2 inches around the smaller vessel, which space is filled with a refrigerating mixture. A vessel, 2 inches in height, is also placed above, filled with the same mixture. At one time an escape-pipe had been in use at the lower part of the apparatus, but it was found more practicable to empty it after each operation by a siphon. The cold mixture used consists of three parts of ice in small pieces and one part of powdered rock salt, its cheapness being a considerable advantage. The lowest temperature obtained in the interior of the apparatus was below 10° Fahrenheit, although a still lower temperature could have been arrived at. Small thermometers were inserted in the stones, and although two hours sufficed to bring these to the temperature of the surrounding air, the stones were subjected to the process during a period of three hours. Felt or sawdust was used to procure isolation from the outer air, the former being more effectual, but the latter preferable on account of its cheapness.

In the selection of the stones, as well as in the general conduct of the experiments, Herr Blümcke had the advantage of the advice of Professor Gottgetreu, the trials being conducted in the laboratory of Professor Von Beetz. The stones were in cube form, the length of the sides being about 3¼ inches, and the surfaces roughly dressed. Two specimens were tested in each case, and one of them was completely saturated with distilled water. Boiling was, however, avoided, so as not to expose the material to a degree of heat which it is not in practice called to endure. When a material is very porous it is impossible to freeze it when thoroughly saturated. After removal from the refrigerating apparatus the cubes were placed in a small trough, covered with water, and left there three hours, so as to again be brought to the temperature of the room. When taken out the stones were covered with a coating of hoar frost, and if then left for some time in water a loosening of small particles was perceptible in the portions not capable of resisting frost. Before the next subjection of the stones to the refrigerating process the surfaces were gently rubbed with a feather. Herr Blümcke repeated the process until distinct traces of injury were visible, such as cracks, peeling, loosening of corners, &c. If a stone had been ten times subjected to the frost, with such traces appearing, the quantity of the mass separated after the evaporation of the water was ascertained, and the process continued until destruction commenced. A second cube was subjected to a stream of water during one hour upon three sides. In this case there was no attempt made to ascertain the loss of volume, but the application of the water was continued until injury became apparent. These external appearances were quite the same as if the stone had been saturated, but were considerably later in manifesting themselves.

From these experiments Herr Blümcke has deduced the theory that a material has higher properties of resistance to frost, according to the restriction of the loss in weight, caused by the repeated application of the freezing process. In trials made upon sandstone the following

results were obtained. In all cases cracks were finally visible which ran close to each other (parallel to one or several edges), and produced crumbling when the operations were persevered with.

Name.	Specific gravity.	Water taken up in per cent. of volume.	Number of freezings.	Loss in weight. Grammes.
1. White, Langenzenn	1.97	22.6	2	5.0088
2. Green, Ellingen	2.00	24.1	3	0.7446
3. Grey, Oberdachstetten	2.06	21.1	3	0.5910
4. Yellow, Lengast	1.83	32.6	3	0.4562
5. Red and white striped, Waldaschaff.	2.22	11.0	3	0.4067
6. Green sandstone, Albech	2.14	18.1	4	0.2835
7. Yellow, origin unknown	2.34	14.6	6	0.2541
8. Yellow, Zeil	2.18	13.9	8	0.1058
9. Grey, Gründen	2.44	13 7	13	0.0835
10. Red, Rothenfels, A. M	2.31	11.3	24	0.0820

Large pieces were detached from No. 1, and cracks appeared all over Nos. 2 and 3. On No. 4 there were two kinds of coatings, a darker one, which broke off more than the other, and a lighter one, which showed cracks. Nos. 6 and 8 peeled on the surface, and No. 7 was much cracked. After the thirteenth freezing of the ninth type a splinter became detached from one corner, but cracks parallel to the edge were not visible till after the forty-third freezing.

By proceeding in this way it is not necessary to wait for the visible destruction of the material. Coupled with the definition of the degree of resistance to frost is an approximate estimate of the period a stone will last, as it is not difficult to arrive at the number of alternations during an average winter between frost and thaw. When thoroughly saturated stones are tested, the results are applicable to the most unfavorable circumstances, and are consequently the more reliable. Should a material not show injury at the temperature applied, this fact does not establish its power of resisting frost, but renders advisable the trial of a still lower temperature; in no case, however, below the range to which, in practice, the stone would be subjected. Finally, Herr Blümcke does not claim that he has solved all the questions connected with this interesting subject, but considers that his illustration of what may be done with simple means, by skillful and capable hands, may not be devoid of value to the cause of science.

COMPARATIVE EXPERIMENTS ON THE WELDING OF STEEL AND WROUGHT IRON.

By J. BAUSCHINGER.

These experiments were undertaken by the author at the instance of an engineering firm.

Similar experiments had been previously made at the Royal Mechanical-Technical Experimental Institute at Berlin, and by Mr. W. Hupfeld, at Prevali, which gave very different results; those at Berlin being very unfavorable, those at Prevali very favorable, as regards the welding capacity of steel (*Flusseisen*). The author recapitulates the main results of these tests before describing those made by himself. The materials used in the latter were steel (*Flusseisen*), from the "Peine" ironworks at Hanover, and bar iron of various sections from the "Neuhoffnungshuette," near Herbauer, in Nassau.

The test-pieces were flat, square, and round in section, the largest being 80 × 30 millimeters (3.149 × 1.181 inch). Each

piece was cut in two cold, swelled up on the anvil when hot 5 to 10 millimeters (0.196 to 0.392 inch), and, after heating to the proper degree, the two portions were laid on each other, and welded together by hand or steam hammer.

Some preliminary studies were made in the laboratory of the college to ascertain the best method of welding, and the best flux for steel; quartz sand answered the latter purpose, while it was found that a rather less degree of heat was required for steel than for wrought iron; a pure coal fire was used.

In the chief experiments the steam hammer was employed. Every piece, after welding, was tested in the usual way for tensile strength; the limit of elasticity, contraction, extension, and ultimate strength being determined, the same quantities having been measured for pieces of exactly similar quality, section, and length, but without a weld.

The results are given in a tabular form. Both for steel and iron the limit of elasticity is nearly always reduced by welding, and this is, without exception, the case as regards the extension, the contraction of welded is less than that of unwelded pieces when the fracture takes place in the welded portion.

The general conclusions arrived at are, that for steel the best welding temperature is just at the transition from a red to a white heat; a quick fire and smart handling are necessary, as the piece should not be long in the fire.

Analyses were made of three samples, one of which welded admirably, the second badly, and the third not at all.

The author is of opinion that, in the case of mild steels, such as those tested, with a low carbon, intended to take the place of bar iron, success, or otherwise, in welding, depends less on the chemical composition than on the mechanical treatment.—*Abstract of Inst. of Civil Engineers.*

IMPROVEMENTS IN THE ARRANGEMENT AND RATING OF CURRENT-METERS, AND IN THE METHOD OF CALCULATING DISCHARGES.

By CHARLES RITTER.

From "Annales des Ponts et Chaussées," for Institution of Civil Engineers.

A DETAILED account is given by the author of the elaborate investigations which he conducted, with the object of rendering more serviceable the two gauging instrument generally employed in France, namely, Darcy's gauge-tube, and Woltmann's current-meter as improved by Mr. Baumgarten; for the purpose of facilitating the rating of these instruments; and lastly, for improving the methods of calculating the discharge from the indications furnished by the instruments. The ordinary type of gauge-tube is awkward to handle; and gauging with a current-meter which has to be drawn up out of the water for each reading is a slow process, especially at great depths. Moreover, the rating of these instruments has hitherto been frequently so difficult, slow, and costly, that either the rating has been dispensed with, thus introducing an uncertainty in the results, or the most favorable time for gauging has slipped by during the preliminary operations.

The gauge-tube adopted has the pressure-gauge distinct from the nozzles, which are connected together by india-rubber tubes. The rod carrying the nozzles is thereby made much more handy, whilst the observer can suspend the pressure-gauge so as to keep the summits of the two columns of water always in view, whose oscillations are considerably reduced by means of a regulator interposed between each india-rubber tube and the gauge. The nozzle pointing towards the stream has not been altered in type, but its best form consists of a straight tube 0.2 inch in diameter, and 4 to 6 inches long, tapered at the extremity, and presenting a cylindrical orifice of 0.08 inch in diameter throughout the tapered portion. The side nozzle, however, has been replaced by a statical mouthpiece, which indicates the pressure

corresponding to the surface-level of the current without needing any correction. The mouthpiece adopted for this purpose consists of a tube, 4 inches long and 0.4 inch in diameter, open at both ends, and having a lateral orifice in the middle, from 0.04 to 0.08 inch in diameter, round which the second connecting-tube is soldered. Each connecting-tube consists of two portions, one portion, a rigid copper tube, and the other, a flexible india-rubber tube. The copper tubes carry the nozzles at their lower extremities, and have an air-chamber at their upper ends, with a stop-cock at the top. Each air-chamber communicates with one of the india-rubber tubes by a lateral opening. The air-chambers receive the bubbles of air, either introduced by accidents in the manipulation or contained in the water itself. The stop-cocks serve for adjusting the instrument. The copper tubes should not be less than about $\frac{1}{4}$ inch diameter, to allow of the ready passage of air-bubbles into the air-chambers. The india-rubber tubes are made about $\frac{1}{8}$ inch internal diameter, for though they are little liable to receive air-bubbles, a very small diameter would impede the establishment of an equilibrium in the pressure-gauge. Their external diameter is made 0.4 inch, so that they may be bent without collapsing, which would impede the flow. The two connecting-tubes are enclosed in a hollow rod, 1 inch in diameter, which is provided with a vane at the bottom to facilitate the adjustment of the line of the nozzles. The pressure-gauge is furnished with a third tube to facilitate certain operations of rating. By the adoption of the statical mouthpiece, no rating is required, for the difference in the height of the two columns of water in the pressure-gauge h, is equal to $\frac{V^2}{2g}$, without any coefficient being required in the equation. Also the coefficient of gauge-tubes with any other side mouthpieces can be easily determined by connecting the mouthpiece with the third tube of the pressure-gauge and observing the heights of the three columns of water in different points of the stream. The most convenient instrument of the type described has a total length of $6\frac{1}{2}$ feet, and is not suitable for depths exceeding $3\frac{1}{2}$ feet; but by screwing on a lengthening piece to the rod it can be used for depths of 5 to 6 feet. This type of instrument is not suitable for considerable depths, both on account of the difficulty of handling an apparatus of over 10 feet in length when raised out of water, and also owing to the escape of air-bubbles when the pressure is reduced in the tubes by immersion, necessitating constant readjustments. These difficulties, however, might be obviated by using a different gauge-tube for each separate group of depths comprised within intervals of 5 feet.

The current-meter adopted has four spiral vanes, and is provided with an electrical recorder for every fifty revolutions. It is inclosed within a hollow copper cylinder, 8 inches long, open at both ends, having a diameter of about $4\frac{1}{2}$ inches, just large enough not to interfere with the revolution of the vanes. The cylinder protects the current-meter from the disturbing influences of oblique currents, and it facilitates the free suspension of the instrument which is directed in the line of the current by a large flat plate behind. The instrument is suspended in small depths, or near the surface by a hollow copper rod; but in greater depths, when the length of rod necessary would be inconvenient, it is hung from a cord formed of two insulated copper wires, which convey the electrical current. The current-meter is kept in position by a second cord (kept tight by a weight at the bottom of the river, and a winch above) down which it descends, being guided by rollers. The rating, besides being conducted in the usual manner by drawing the meter through still water, was effected, for small velocities, by forming a very regular artificial current; and it was also obtained in the river itself, during the experiments, by placing the front nozzle of a gauge-tube in front of the axis of the current-meter and comparing the results of the two methods. When the velocity of a current is very small, the eddies produce almost as much effect as the direct current, so that the action of the vanes of the meter is uncertain; and consequently, it is unadvisable to employ the current-meter for gauging currents having velocities under 1 to $1\frac{1}{3}$ foot per second.

Owing to the variations and irregularities in the current, the velocities given by the instruments are always greater than the direct motion of the stream.

Sometimes, also, under exceptional circumstances, the recorded velocities are too low. Accordingly, in order to make allowance for these discrepancies between the real and calculated results, the mean of two-thirds of the largest velocities, and the mean of two-thirds of the least velocities are taken, and half the sum of these two means is accepted as the actual mean velocity in the section. The mean velocities throughout the whole section can be obtained by tracing the lines of equal velocity, as gathered from the observations, and prolonging these lines, in accordance with the indications furnished by the adjacent lines, to those parts of the section which cannot be reached by the instruments. The article concludes with some practical applications of the above methods of gauging, in illustration of the processes adopted and the degree of accuracy attained.

THE LUMINIFEROUS ÆTHER.

By DE VOLSON WOOD, C. E., M. A.

From the "Philosophical Magazine."

Two properties of the luminiferous æther appear to be known and measurable with a high degree of accuracy. One is its ability to transmit light at the rate of 186,300 miles per second,* and the other its ability to transmit from the sun to the earth a definite amount of heat energy.

In regard to the latter, Herschel found, from a series of experiments, that the direct heat of the sun, received on a body at the earth capable of absorbing and retaining it, is competent to melt an inch in thickness of ice every two hours and thirteen minutes. This is equivalent to nearly 71 foot-pounds of energy per second.

In 1838 M. Pouillet found that the heat energy transmitted from the sun to the earth would, if none were absorbed by our atmosphere, raise 1.76 grammes of water 1° C. in one minute on each square centimeter of the earth normally exposed to the rays of the sun.†

This is equivalent to 83.5 foot-pounds of energy per second, and is the value used by Sir William Thomson in determining the probable density of the æther.‡ Later determinations of the value of the solar constant by MM. Soret, Crova, and Violle have made it as high as 2.2 to 2.5 calories. But the most recent, as well as the most reliable, determination is by Professor S. P. Langley, who brought to his service the most refined apparatus yet used for this purpose, and secured his data under favorable conditions; from which the value is found to be 2.8 ± calories * with some uncertainty still remaining in regard to the first figure of the decimal. We will consider it as exactly 2.8 in this analysis, according to which, there being 7,000 grains in a pound and 15.432 grains in a gramme, we have for the equivalent energy

$$\frac{2.8\times15.432}{7{,}000}\times\frac{9}{5}\times\frac{772\times144}{0.155\times60}=$$

133 foot-pounds

per second for each square foot of surface normally exposed to the sun's rays, which value we will use. Beyond these facts, no progress can be made without an assumption. Computations have been made of the density, and also of the elasticity, of the æther founded on the most arbitrary, and in some cases the most extravagant, hypotheses. Thus, Herschel estimated the stress (elasticity) to exceed

$$17\times10^{9}=(17{,}000{,}000{,}000)\text{ pounds per square inch};\dagger$$

and this high authority has doubtless caused it to be widely accepted as approximately correct. But his analysis was founded upon the *assumption* that

* Professor Michelson found the velocity of light to be 299,740 meters per second in air, and 299,828 meters in a vacuum, giving an index of refraction of 1,000,265. "Journal of Arts and Science," 1879, vol. xviii., p. 390.

† *Comptes Rendus*, 1838, tom. vii. pp. 24-26.

‡ "Trans. Roy. Soc. of Edinburgh," vol. xxi. part 1.

* *Am. Journ. of Arts and Science*, March, 1883, p. 195. Also *Comptes Rendus*.

† "Familiar Lectures," p. 282.

the density of the æther was the same as that of air at sea level, which is not only arbitrary, but so contrary to what we should expect from its non-resisting qualities, as to leave his conclusion of no value. That author also erred in assuming that the tensions of gases were as the wave-velocities in each, instead of the mean square of the velocity of the molecules of a self-agitated gas; but this is unimportant, as it happens to be a matter of quality rather than of quantity. Herschel adds, "Considered according to any hypothesis, it is impossible to escape the conclusion that the æther is under great stress." We hope to show that this conclusion is not warranted; that a great stress necessitates a great density; but that both may be exceedingly small. A great density of the æther not only presents great physical difficulties, but, as we hope to show, is inconsistent with the uniform elasticity and density of the æther which it is believed to possess; and every consideration would lead one to accept the lowest density consistent with those qualities which would enable it to perform functions producing known results.

In a work on the "Physics of Æther," by S. Tolver Preston, it is estimated that the probable inferior limit of the tension of the æther is 500 tons per square inch, a very small value compared with that of Herschel's. But the hypothesis upon which this author founded his analysis was—The tension of the æther exceeds the force necessary to separate the atoms of oxygen and hydrogen in a molecule of water; as if the atoms were forced together by the pressure of the æther, as two Magdeburg hemispheres are forced together by the external air when there is a vacuum between them. This assumption is also gratuitous, and is rejected for want of a rational foundation.

Young remarks: "The luminiferous æther pervading all space is not only highly elastic, but absolutely solid."* We are not certain in what sense this author considered it as solid; but if it be in the sense that the particles retain their relative positions, and do not perform excursions as they do in liquids, it is a mere hypothesis, which may or may not have a real existence. If it be in the sense that the particles suffer less resistance to a transverse than to a longitudinal movement, there are some grounds for the statement, as shown in circularly-polarized light. Bars of solids are more easily twisted than elongated, and, generally, the shearing resistance is less than for a direct stress. It certainly cannot be claimed that the compressibility of the æther (in case we could capture a quantity of it) is less than that of solids.

Sir William Thomson made a more plausible hypothesis, by assuming that "the maximum displacement of the molecules of the æther in the transmission of heat energy was $\frac{1}{50}$ of a wave length of light, the average of which may be taken as $\frac{1}{50000}$ of an inch." Hence the displacement was assumed to be $\frac{1}{2500000}$ of an inch; by means of which he found the weight of a cubic foot to be $\frac{2}{3}\times10^{-20}$ of a pound.* We also notice that one Belli estimated the density of the æther to be $\frac{1}{2}\times10^{-19}$ of a pound;† but M. Herwitz, assuming this value to be too small and Thomson's as too large, arbitrarily assumed it as 10^{-18} of a pound per cubic foot; but arbitrary values are of small account unless checked by actual results.

We propose to treat the æther as if it conformed to the Kinetic Theory of Gases, and determine its several properties on the conditions that it shall transmit a wave with the velocity of 186,300 miles per second, and also transmit 133 foot-pounds of energy per second per square foot. This is equivalent to considering it as gaseous in its nature, and at once compels us to consider it as molecular; and, indeed, it is difficult to conceive of a medium transmitting light and energy without being molecular. The Electromagnetic Theory of Light suggested by Maxwell, as well as the views of Newton, Thomson, Herschel, Preston, and others, are all in keeping with the molecular hypothesis. If the properties which we find by this analysis are not those of the æther, we shall at least have determined the properties of a substance which might be substituted for the æther, and secure the two results already named. It may be asked, Can the Kinetic theory, which is applicable to gases in which

* "Young's Works," vol. i. p. 415.

* *Phil. Mag.*, 1855 [4] ix. p. 39.

† Cf. *Fortschritte der Physik*, 1859.

waves are propagated by a to-and-fro motion of the particles, be applicable to a medium in which the particles have a transverse movement, whether rectilinear, circular, elliptical, or irregular? In favor of such an application, it may be stated that the general formulæ of analysis by which wave motion in general, and refraction, reflection, and polarization in particular, are discussed, are fundamentally the same; and in the establishment of the equations the only hypothesis in regard to the path of a particle is—It will move along the path of least resistance. The expression $V^2 \propto e \div \delta$ is generally true for all elastic media, regardless of the path of the individual molecules. Indeed, granting the molecular constitution of the æther, is it not probable that the Kinetic theory applies more rigidly to it than to the most perfect of the known gases? *

The 133 foot-pounds of energy per second is the solar heat energy in a prism whose base is 1 square foot and altitude 186,300 miles, the distance passed over by a ray in one second; hence the energy in 1 cubic foot will be

$$\frac{133}{186{,}300 \times 5{,}280} = \frac{4}{3 \times 10^7} \text{foot-pounds}. \quad (1)$$

Where results are given in tenth-units of high order, as in the last expression, it seems an unnecessary refinement to retain more than two or three figures to the left hand of the *tens;* and we will write such expressions as if they were the exact results of the computations.

If V be the velocity of a wave in an elastic medium whose coefficient of elasticity, or in other words, its tension, is e and density δ, both for the same unit, we have the well-known relation

$$V = \sqrt{\frac{de}{d\delta}}.$$

And for gases we have

$$e = \delta^\gamma,$$

where $\gamma = 1.4$; and the differential of the latter substituted in the former gives

$$V = \sqrt{\frac{\gamma e}{\delta}}. \quad . \quad . \quad . \quad . \quad (2)$$

The tension of a gas varies directly as the kinetic energy of its molecules per unit of volume. If v^2 be the mean square of the molecules of a self-agitated gas, we have

$$e \propto \delta v^2, \text{ or } v^2 = x\frac{e}{\delta}, \quad . \quad . \quad (3)$$

where x is a factor to be determined. Equations (2) and (3) give

$$v^2 = \frac{x}{\gamma} V^2. \quad . \quad . \quad . \quad (4)$$

Assuming, with Clausius, that the heat energy of a molecule due to the action of its constituent atoms, whether of rotation or otherwise, is a multiple of its energy of translation, we have for the energy in a unit of volume producing heat,

$$\tfrac{1}{2} y \delta v^2,$$

where y is a factor to be determined. If c be the specific heat of a gas, w its weight per cubic foot at the place where $g = 32.2$, J. Joule's mechanical equivalent, τ its absolute temperature; then the essential energy of a cubic foot of the medium will be $cw\tau J$; and observing that $w = g\delta$, we have

$$\tfrac{1}{2} y \delta v^2 = cg\delta\tau J, \quad . \quad . \quad . \quad (5)$$

which, reduced by (4), gives

$$xy = \frac{2cg\gamma\tau J}{V^2}, \quad . \quad . \quad . \quad (6)$$

the second member of which is constant for a given gas. To find its value we have

	Hydrogen.	Air.	Oxygen.
Specific heat* . .	3.4093	0.2375	0.2175
Velocity of sound, feet per second, at $\tau = 493.2°$ . .	4,163	1,090	1,040

and $g = 32.2$, $\gamma = 1.4$, $J = 772$. These, substituted in the second member of (6), give

xy for hydrogen.....	6.599
" air.....	6.706
" oxygen.....	6 596
	3)19.901
Mean.....	6.63

This value, which is nearly constant for the more perfect gases, we propose to call *the modulus of the gas*, and represent

* See also remarks by G. J. Stoney, *Phil. Mag.*, 1868 [4] xxxvi. pp. 132, 133.

* Stewart on "Heat," p. 229.

it by μ; and for the purposes of this paper we will use

$$\mu=6.6.$$

This relation of the product xy being a constant, has, so far as we are informed, been overlooked by physicists, and is worthy of special notice, since it determines the value of one of the factors when the other has been found. Krönig, Clausius,* and Maxwell give for x the constant number 3, but variable values for y.†

We are confident that the value of x is not strictly constant; or if it is, it exceeds 3, since the effect of the viscosity of a gas would necessitate a larger velocity to produce a given tension than if it were perfectly free from internal friction. For our purpose, it will be unnecessary to find the separate values of x and y; but if we have occasion to use the former in making general illustrations, we will call it 3, as others have done heretofore. If the correct value of x exceeds 3, it will follow that the velocity of the molecules exceeds the values heretofore computed.‡ According to Thomson, Stokes showed that in the case of circularly polarized light the energy was half potential and half kinetic;§ in which case $y=2$, and therefore $x=3.3$.

The energy in a cubic foot of the æther at the earth being given by (1) and (5), we have, by the aid of (4),

$$\tfrac{1}{2}y\delta v^2=\tfrac{1}{2}\mu\frac{\delta}{\gamma}V^2=\frac{4}{3\times10^7}; \quad . \quad . \quad (8)$$

$$\therefore\delta=\frac{4\times1.4\times2}{3\times10^7\times6.6\times(186{,}300\times5280)^2}=\frac{2}{35\times10^{24}}\text{ lb.}, \quad . \quad . \quad (9)$$

which is the mass of a cubic foot of the æther at the earth, and which would weigh at the place where $g=32.2$ about

$$w=\frac{2}{10^{24}}\text{ of a pound,} \quad . \quad . \quad (10)$$

compared with which Thomson's value is less than 4,000 times this value. Thomson remarked that the density could hardly be 100,000 times as small—a limit so generous as to include far within it the value given in (9). According to equation (10), a quantity of the æther whose volume equals that of the earth, would weigh about $\frac{1}{20}$ of a pound. If a particle describes the circumference of a circle in the same time that a ray passes over a wave-length λ, the radius of the circle will be, using equation (4),

$$r=\frac{vt}{2\pi}=\sqrt{\frac{x}{\gamma}}.V.\frac{\lambda}{2\pi V}=\tfrac{1}{43}\lambda,$$

or the displacement from its normal position will be about $\frac{1}{43}$ of a wave-length, or about $\frac{1}{2150000}$ of an inch at the earth.

Eliminating V between (2) and (8) gives

$$e=\frac{8}{3\mu\times10^7}=\frac{4}{10^8} \quad . \quad . \quad . \quad (11)$$

for the tension of the æther per square foot at the earth, and is equivalent to about 1.1 of a pound on a square mile. The tension of the atmosphere at sea level is more than 30,000,000,000 times this value. It somewhat exceeds the tension of the most perfect vacuum yet produced by artificial means, so far as we are informed. Crookes produced a vacuum of .02 millionth of an atmosphere* without reaching the limit of the capacity of the pumps; and Professor Rood produced one of $\frac{1}{300000000}$ of an atmosphere† without passing the limit of action of his apparatus. The latter gives a pressure per square foot of $\frac{14.7\times144}{390000000}=\frac{1}{180000}$ of a pound. This, in round numbers, is 140 times the value given in equation (11). Even at this great rarity of the atmosphere, the quantity of matter in a cubic foot of the air would be some 200 million million times the quantity in a cubic foot of the æther—such is the exceeding levity of the æther.

Admitting that the æther is subject to

* *Phil. Mag.*, 1857 [4] xiv. p. 123.

† "Theory of Heat," pp. 314 and 317. Maxwell states that the value for y is probably equal to 1.634 for air and several of the perfect gases. This would make $x=4$ nearly.

‡ Maxwell gives for the mean square of the velocities (or, in other words, the velocity whose square is the mean of the squares of the actual velocities) of the molecules, in feet per second at 493.2° F. above absolute zero, hydrogen 6,232, oxygen 1,572, carbonic oxide 1,672, carbonic acid 1,570. *Phil. Mag.*, 1873, p. 68. Our equation (4) gives for air 1,593.

§ *Phil. Mag.* 1855 [4] ix. p. 37.

* "On the Viscosity of Gases at High Exhaustions," by William Crookes, F. R. S., "Phil. Trans. Roy. Soc.," part ii. (1881), p. 400: "Going up to an exhaustion of 02 millionth of an atmosphere, the highest point to which I have carried the measurements, although by no means the highest exhaustion of which the pump is capable."

† *Journ. of Arts and Science*, 1881, vol. xxii., p. 90.

attraction according to the Newtonian law, and of compression according to the law of Mariotte, we propose to find *the relation between the density of the æther at the surface of an attracting sphere and that at any other point in space*, providing that the sphere be cold and the only attracting body, and the gas considered the only one involved.

Let δ_0, e_0, w_0 be respectively the density, elasticity and weight of a unit of the medium, whether æther, air, or any other gas at the surface of the sphere; δ, e, w, the corresponding quantities at a distance z from the surface of the sphere; r the radius of the sphere, g_0 the acceleration due to gravity at its surface, and g that at distance $r+z$ from the center of the sphere. Then

$$\frac{\delta}{\delta_0}=\frac{e}{e_0}=\frac{w}{g}\div\frac{w_0}{g_0}$$

and

$$g=g_0\frac{r^2}{(r+z)^2};$$

$$\therefore\ e=\frac{e_0}{w_0}\cdot\frac{g_0}{g}w=\frac{e_0}{w_0}\frac{(r+z)^2}{r^2}w. \quad . \quad (12)$$

But

$$de=-wdz=-g\delta dz \quad . \quad . \quad (13)$$

$$\therefore\ \frac{de}{e}=-\frac{g_0\delta_0}{e_0}\cdot\frac{r^2}{(r+z)^2}dz.$$

Integrating between e and e_0, $r+z$ and r, we have

$$e=e_0\varepsilon^{-\frac{g_0\delta_0}{e_0}\cdot\frac{rz}{r+z}}, \quad . \quad . \quad (14)$$

$$\delta=\delta_0\varepsilon^{-\frac{g_0\delta_0}{e_0}\cdot\frac{rz}{r+z}}. \quad . \quad . \quad . \quad (15)$$

Neglecting the attraction of the earth for the æther, and considering the sun as the only attracting body, we have g_0 at the sun 28.6×32.2, and at the earth, $z=210r$, $r=441{,}000$ miles, the sun's radius; $\delta=\frac{2}{3^5}\times10^{-24}$, equation (9), and $e=\frac{4}{3^3}\times10^{-6}$; and these, in (14) and (15), give

$$e=e_0\varepsilon^{\frac{28.6\times32.2\times2\times33\times10^6}{4\times35\times10^{24}}\times\frac{210}{211}\times\times441{,}000\times5280}$$

$$=e_0^{\frac{1}{1{,}000{,}000}}\text{ nearly}, \quad . \quad . \quad (16)$$

and

$$\delta=\delta_0\varepsilon^{\frac{1}{1{,}000{,}000}}\text{ nearly}, \quad . \quad . \quad (16')$$

for the tension and density of the æther at the surface of the sun under the conditions imposed. But the millionth root of ε is practically unity; hence the elasticity and density at the sun is practically the same as at the earth.

Now, starting at the sun with this result, and finding the density at a distance z from it, then making z infinite, we shall get about the 995,000 root of ε, the value of which is also sensibly equal to unity; hence the density at infinity would be sensibly the same as at the surface of the sun, the difference in the densities at the sun and at infinity being less than $\frac{1}{1000000}$ part of that at the sun. In order to make the density vary sensibly with the distance, the attraction of the central body must be something like a million times as great as that of the sun, or have a diameter a million times as large; but there being no such known body, therefore *the density and tension of the æther may be considered uniform throughout space.* Such has been our conception of it, and it is an agreeable surprise to find it so fully confirmed by analysis.

If the density were uniform, the weight of a given volume of it would vary as the force of gravity. At the surface of the sun a cubic foot would weigh [equation (10) multiplied by 28.6, or] 57×10^{-24}; hence, for a height h it would weigh

$$\frac{57}{10^{24}}\int_0^h\frac{r^2}{(r+z)^2}dz=\frac{57}{10^{24}}\cdot\frac{rh}{r+h}, \quad . \quad (17)$$

which for $h=\infty$ becomes $\frac{13}{10^{24}}$ of a pound, which is the pressure upon a square foot of the sun of a column of infinite height under the conditions imposed. This would compress the first foot of the column about $\frac{1}{1000000}$ of its length, and would cause a corresponding increase in the density, the value of which, after this compression, will be found by multiplying the value given in equation (9) by $\frac{999999}{1000000}$, which will leave the result sensibly the same as before. Hence, from this standpoint, we again conclude that the density of the æther may be considered as sensibly uniform throughout space, providing its temperature be essentially uniform.

If we assume that the law of the resistance by which the æther opposes the motion of a body varies as the square of

the velocity of the body, we are still unable to assign the coefficient which will give the numerical value; but it is safe to assume that the entire mass of the æther occupying the path of a body moving through it, will not have a velocity imparted to it exceeding that of the body; but, to be on the safe side, we will assume that it imparts a velocity equal to itself. The energy thus imparted will be lost to the body. To simplify the case, consider a planet moving in a circular orbit: r the radius of the planet, d its distance from the sun, D its specific gravity compared with water as unity, v_1 the velocity in its orbit; then the mass of æther occupying the place of the planet during one revolution about the sun will be, using equation (9),

$$\frac{2}{35\times10^{24}}\pi r^3\times 2\pi d,$$

which, multiplied by $\frac{1}{2}v_1^2$, will give the energy imparted to it. The kinetic energy of a planet, neglecting its rotation, will be

$$\tfrac{4}{3}\pi r^3\times 62\tfrac{1}{2}\mathrm{D}\times\frac{v_1^2}{2g}.$$

Dividing the former, after multiplying it by $\frac{1}{2}v_1^2$, by the latter, gives

$$\frac{1}{7\times10^{24}}\cdot\frac{d}{r\mathrm{D}} \quad . \quad . \quad . \quad . \quad (18)$$

for the fraction of the energy lost during one revolution about the sun. Applying this to the earth, we have

$$d\div r\mathrm{D}=93{,}000{,}000\div 3{,}912\times 5\tfrac{1}{2}=43{,}000,$$

and (18) becomes

$$\frac{6}{10^{32}} \text{ nearly,} \quad . \quad . \quad (19)$$

for the fraction of the energy lost in one year; and hence *at this rate* would require more than 1,666,000 trillion (1,666,000,000,000,000,000,000) years to bring it to rest.

Equation (18) is not applicable to the resistance offered to a comet, on account of the elongated orbit of the latter; but some idea of the effect of the resistance of the æther to the movement of a comet may be found by considering what it would be if the orbit were circular, having for its radius the perihelion distance. According to Professor Morrison, the perihelion distance of the great comet (6), 1882,* was 716,200 miles, its aphelion distance will be 5,000,000,000 miles, the diameter of its nucleus shortly before disappearing on the solar disk was 7,600 miles, the velocity at perihelion 295 miles per second, and at aphelion 75 feet per second. But little is known in regard to the density of comets; but, to be on the safe side we will assume it as $\frac{1}{1000}$ that of water. This data will reduce (18) to 13×10^{-18} for the fraction of energy lost during one of its revolutions about the sun; and as it would make a revolution in, say, 20 hours, it would lose in one of our years about 57×10^{-16} of its energy, *at which rate* it would go on for 170 trillions of years. Similarly, at its aphelion its *rate* of loss would be less than $\frac{1}{4}\times10^{-15}$ of its energy in more than 2,000 years—the time of one revolution in its orbit.

The most careful observations and calculations have failed to detect any effect due to the resistance of matter in space; and the above analysis shows that, within historic times, it has in any case scarcely amounted to an infinitesimal, certainly not sufficient to be measured. And when we consider that our assumptions have been very largely on the unfavorable side, and, further, that the energy imparted to the æther may partly, at least, be restored to the body, we assume that its resistance never can be measured. Laplace, when he found that the force of gravitation, if propagated by an elastic medium, must have a velocity exceeding 100 million times that of light, concluded that astronomers might continue to consider its action as instantaneous (*Mécanique Céleste*, B. x., ch. viii., p. 22, 9,035); so may we, with nearly as much confidence, continue to consider the resistance of the æther as *nil*.

Equation (6) gives

$$c\tau=\frac{6.6(186{,}300\times5{,}280)^3}{2\times32.2\times1.4\times772}=92\times10^{12} \quad (20)$$

from which the specific heat of the æther may be found if its temperature were known. M. Fourier, the first to assign a value to *the temperature of space*, assumed it to be somewhat inferior to the temperature at the poles of the earth

* "Monthly Notices of the Royal Astronomical Society," vol. xliv. 2, p. 54.

or about 50° C. to 60° C. below zero.* M. Pouillet, considering the atmosphere as a diathermanous medium, capable of absorbing in different degrees the radiant heat from the sun and the dark heat from the earth, deduced for the heat of space—or, as he and Fourier called it, the stellar heat—approximately—142°C.† (−287° F.), which is about 174° F. above absolute zero. It is well known that Pouillet's data were imperfect, several important elements being neglected, notably that of the humidity of the air; still, it is not only the first, but, so far as we know, the only attempt to formulate this relation. It served to show what has since been indicated by more direct experiments, that the temperature of space is very low. The delicate experiments of Professor Langley, before referred to, show a great difference in the degree of absorption by our atmosphere of different wave-lengths. The mean of the values for nine different wave-lengths, treated by M. Pouillet's formula, gives 139° F. above absolute zero, and the smallest value of absorption, which was for the infra-red, gives only 71° F. above absolute zero for the heat of space.

The heat of space may be considered as composed of three parts: (1) stellar heat, (2) the heat contained in the dark matter of space, (3) the essential heat of the æther.

1. By the stellar heat we mean the heat received directly from the stars. It is a matter of easy calculation that, if the 50,000,000 of stars supposed to be visible with the most powerful telescopes were all at the distance of the nearest fixed star (a Centauri), or 221,000 astronomical units from the earth, and if each radiated the same amount of heat as our sun, the intensity varying as the inverse squares of the distances, the earth would receive from them all less than $\frac{1}{1000}$ as much heat as it now receives from the sun. And when we consider that only a very few stars are within measurable distances, and that the remote ones may be, when compared with these, well-nigh infinitely distant, it is evident that the amount of heat received from the stars is insignificant, and may be discarded at the earth.

2. It is certain that there is a large amount of dark matter in space, since the meteoric dust and meteorites must come from beyond our atmosphere. The zodiacal light is supposed to be an evidence of meteoric matter between the earth and sun. The tails of comets are visible by some action of light upon some kind of matter. Matter in space not exposed to the rays of the sun will be at about the same temperature as the æther; but if in the rays of the sun and destitute of an atmosphere at the distance of the earth from the sun, its temperature would be very low. If present laws can be extended so far, and the earth were without an atmosphere, and the heat received were not conducted away, it has been computed that the mean temperature at the equator would be about −70° C. (−94° F.); and at the poles—221° C.,* or 114° F. above absolute zero. The last result is obtained on the supposition that the poles receive heat directly from the sun a part of the year; it is further shown that if the poles were never exposed to the rays of the sun, the temperature would fall to that of the æther of space. But the data is not uniform, and there is too large an extension of empirical formulæ to satisfy one that the above numerical results are reliable: still they point more and more strongly to a temperature not many degrees above absolute zero.

3. By the essential heat of the æther we mean the temperature which would be indicated by a thermometer graduated from absolute zero in a room located in space beyond our atmosphere, whose walls were impervious to the passage of external heat. It is the heat due to the self agitated æther, just as air has a temperature when not exposed to the rays of the sun. If the æther be perfectly diathermanous to the sun's rays, it will receive no heat, on account of the heat of the sun flowing through it, though it may be

* *Ann. der Chemie*, tome xvii, p. 155.

† *Comptes Rendus*, 1838, vol. 7, p. 61. Pouillet's formula is

$$a^{t'} = 1.235\frac{2-b}{2-b'} - 0.489,$$

in which b' = the absorptive power by the atmosphere of the sun's heat,
b = the absorptive power of terrestrial heat,
t' = the temperature of the stellar heat,
a = 1.0077.

If $b=1$, its maximum, $b'=0.2$, we find $t'=-235°$ C. (−391° F.), or 71° F. above absolute zero.

* "Professional Papers of the Signal Service, U. S. A.," Washington, D. C., 1884, No. xii., p. 54.

heated from other sources. As direct evidence of an extremely low temperature of space, we cite the facts in regard to the meteorite which fell at Dharmsalla, India, July 14, 1860.* "The most remarkable thing about it was, while the mass had been inflamed and melted at the surface, the fragments gathered immediately after the fall and held for an instant were *so cold that the fingers were chilled.* This extraordinary assertion, which is contained in the report with no expression of doubt, indicates that the mass of the meteorite retained in its interior the intense cold of the interplanetary space, while the surface was ignited in passing through the terrestrial atmosphere." Since this body had been exposed to the rays of the sun, its temperature must have exceeded that of the space through which it passed, as well as been warmed by the heat developed at its surface, from which it may be inferred that it had been *intensely* cold. Direct investigations, given above, indicate that this temperature is less than 200° F. above absolute zero; and we cannot assert that it is not less than 100° F. above, or even much less.

But, however low be the temperature of the æther, it cannot be absolutely cold, or, in other words, it must have a temperature above absolute zero. for otherwise it would be destitute of elasticity, and hence incapable of transmitting a wave. This is shown by eliminating V between equations (2) and (6), giving

$$c\tau=\frac{\mu}{2g\delta J}e,\dagger \quad . \quad . \quad . \quad (21)$$

in which if $\tau=0$, e will be zero, all the other factors being finite, and if $e=0$, then $V=0$ in (2). Indeed, this principle is so well recognized in physics, that a proof in this place seems superfluous. Being unable, in the present state of our knowledge, to do more than assign the probable superior limit of the temperature, we will, for the purposes of this analysis, assume $\tau=20°$ F., absolute, being confident that the actual value is between $\frac{1}{10}$ of and 10 times this value. This value in equation (20) gives

$$c=46\times10^{11}=4{,}600{,}000{,}000{,}000 \quad (22)$$

for the specific heat of the æther, that of water being unity. This number so vastly—we might say infinitely—exceeds that for any known gas, as to justify one, at first thought, in looking with suspicion upon the applicability of the above analysis to this medium. Assumptions in regard to the absolute temperature will scarcely improve the appearance of this number. If it be assumed that the absolute temperature be only one degree, the number in equation (22) would be only twenty times as large; and if the absolute temperature be assumed at 1,000,000° F., the resulting specific heat would still be more than a million times as large as for hydrogen. A few considerations of other properties of the æther may aid one in being reconciled to this paradoxical result. Is the result any more incredible than the fact, everywhere admitted, that every particle of the æther, in transmitting a wave of light, continually makes 590,000,000,000,000 (6×10^{14} nearly) complete cycles of movements every second, for a wave-length of $\frac{1}{50000}$ of an inch? The number of such complete movements in air for the fundamental c is only 264; and hence the ratio of the former to the latter of these numbers is nearly 2×10^{12}. The ratio of the specific heat given in (22) to that of hydrogen is nearly $1\frac{1}{2}\times10^{12}$, which is not so different from that just given for the ratio of cyclical movements in a second of the æther and air. The velocity of sound in air at 493° F. above absolute zero is about 1,090 feet per second; but if the temperature could be reduced to 20° F., absolute, the law being extended so far, the velocity would be only

$$V=109\sqrt{\frac{20}{493}}=217 \text{ feet};$$

but the velocity of light is 982,000,000 feet per second, a number about $4\frac{1}{2}$ million times the former, and near a million of times that of the velocity in air under ordinary conditions. The ratio of the mass of air in a cubic foot at sea-level to that of a cubic foot of the æther as computed, far exceeds any of these ratios. The fact is, the known qualities of the æther in transmitting light and heat so

* *Comptes Rendus*, 1861, tome liii., p. 1018.

† We note that this equation shows that the specific heat for different gases under the same tension, e, and temperature, τ, varies inversely as the density; and for the same temperature and density the specific heats c will be directly as the tension e. The more perfect gases, as hydrogen, oxygen, and air, conform nearly to this law.

far transcend those of any known terrestrial substance, that we might anticipate the fact that, in regard to magnitude, all its properties will be extremely exceptional when compared with such substances. We must accept substantially the number in equation (22), or subject this medium to different laws than those of gases.

We may deduce this result by another process; thus, since the specific heats of different gases are as the squares of the wave-velocities in the respective substances, the other elements being the same, if the specific heat of air be 0.23, we should have for the specific heat of the æther

$$c=0.23\left(\frac{186300\times 5280}{217}\right)^2=46\times 10^{11},$$

as before. The correct value of the specific heat of air, 0.2375, would give over 47×10^{11}, and nearly 48×10^{11}; but these differences are quite immaterial in this connection, the object being to check the former result, and find chiefly qualitative values.

On the other hand, in order that common air might be able to transmit a wave of the known velocity of light, its specific heat being taken constantly at 0.23, its temperature would be, according to equation (20),

$$\tau=\frac{92\times 10^{12}}{0.23}=4\times 10^{14}\text{ degrees F.}$$

(=400,000,000,000,000° F.).

If the sun were composed of a substance having such specific heat, it could radiate heat at its present rate for more than a hundred millions of centuries without its temperature being reduced 1° F., exclusive of any supply from external sources, or from a contraction of its volume. We know only such substances in the sun as we are able to experiment with in the laboratory; and if there be an exceptional substance in it, we have no means at present of determining its physical properties. It is, moreover, a question whether the æther constitutes an essential part of bodies. We conceive of it only as the great agent for transmitting light and heat throughout the universe.

On account of the enormous value of the specific heat, it will require an inconceivably large amount of heat (mechanically measured) to increase the temperature of one pound of it perceptibly. Thus, if heat from the sun, by passing through a pound of water at the earth, would raise the temperature 100° F. and maintain it at, say, 600° F., absolute, it would, under similar conditions, raise the temperature of one pound of the æther, if its power of absorption be the same as that of water, $\frac{1}{46000000000}$ of a degree.

The distance of the earth from the sun being 210 times the radius of the latter, the amount of heat passing a square foot of spherical surface at the sun will be about 45,000 times the heat received on a square foot at the earth normally exposed to its rays, so that, under the conditions imposed, the temperature would not be a billionth of a degree F. higher at the sun than at the earth. This, then, is a condition favorable to a sensibly uniform temperature, even if heated by the sun's rays. *We* are now inclined to admit that the æther is not perfectly diathermanous to the sun's rays, but that its temperature, however small, may be due directly to the absorption of the heat of central suns; for we begin to realize the fact that the æther may possess many of the qualities of gases, such as a molecular constitution, and hence also mass, elasticity, specific heat, compressibility, and expansibility, although the magnitude of these properties is anomalous. We have already considered its compressibility at the surface of the sun, due to the weight of an infinite column, and found it to be exceedingly small; now, it may be possible that the expansion due to the excess of temperature of a small fraction of one degree at the surface of the sun over that at remote distances will diminish the density as much, or about as much, as pressure increased it, thereby making the density even more exactly uniform than it otherwise would be. According to what we know of refraction, it is impossible for a ray of light to be refracted in passing through the æther only—at least, not by a measurable amount; for not only are the density and elasticity practically uniform, but their ratio is, if possible, even more constant as shown by equations (16) and (16′). But the freedom of the æther molecules may be constrained, or their velocity impeded, by their entanglement with gross matter, such as the gases and transparent solids;

in which case refraction may be produced in a ray passing obliquely through strata of varying densities. Neither is it believed that the æther does, or can, reflect light; for if it did, the entire sky would be more nearly luminous. The rays in free space move in right lines.

The masses of the molecules in different gases being inversely as their specific heats, and as the specific heat of hydrogen is 3.4, and the computed mass of one of its molecules $\frac{11}{18}\times10^{-29}$* of a pound, we have for the computed mass of a molecule of the luminiferous æther,

$$m=\frac{11}{18\times10^{29}}\times\frac{3.4}{46\times10^{11}}=\frac{1}{22\times10^{40}}\text{lb.} \quad (23)$$

The mass of a cubic foot of the æther, equation (9), divided by the mass of a molecule, gives the number of molecules in a cubic foot, which will be

$$n=\frac{2}{35\times10^{34}}\times\frac{22\times10^{40}}{1}=\frac{44}{35}\times10^{18}, \quad (24)$$

which call 10^{18}. This number, though large, is greatly exceeded by the estimated number of molecules in a cubic foot of air under standard conditions, which, according to Thomson, does not exceed 17×10^{25}, a number nearly 17,000,000,000 times as large as that in equation (24); and yet, at moderate heights, the number of molecules in a given volume of air will be less than that of the æther.

Assuming that air is compressed according to Boyle's law, and is subjected to the attraction of the earth, equation (15) will give the law of the decrease of the density. Taking the density of air at sea-level at $\frac{1}{4000}$ of a pound per cubic foot, $e_0=14.7$ lbs. per square inch, $r=20{,}687{,}000$ feet, equation (15) becomes

$$\delta\times\tfrac{1}{4000}\times10^{-345\frac{z}{r+z}}. \quad . \quad . \quad (25)$$

If $z=\infty$, $\delta=\frac{1}{4000}\times10^{-345}$, which would be the limit of the density, and it is a novel coincidence that this limit is nearly identical with the value found for the density at the height of one radius of the earth according to the ordinary exponential law, wherein gravity is considered uniform.*

If the number of the molecules in a cubic foot follows the same law, then at the height z there will be

$$17\times10^{-345\frac{z}{r+z}+25} \quad . \quad . \quad (26)$$

molecules per cubic foot. Similarly, the value of the length of the mean free path would be†

$$2\times10^{345\frac{z}{r+z}-6}\text{ inches.} \quad . \quad (27)$$

By means of these values, the table which appears on the following page may be formed.

The numbers in the third column multiplied by $\frac{1}{4000}$ will give the density (or mass per cubic foot) at the respective altitudes; and the same numbers multiplied by 15 (or, more accurately, 14.7) will give the tension per square inch. According to this law, at an elevation of 300 miles the density of the atmosphere will be somewhat less than the density of the æther as given by equation (9).

To find the height at which the tension of the atmosphere, according to the above law will be the same as that of the

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* Stoney concludes that "it is therefore probable that there are not fewer than something like a unit eighteen (10^{18}) of molecules in a cubic millimeter of a gas at ordinary temperature and pressure" (*Phil. Mag.* 1868 [4] xxxvi. p. 141). According to the Kinetic theory the number of molecules in a given volume under the same pressure and temperature is the same for all gases. The weight of a cubic foot of hydrogen at the temperature of melting ice and under constant pressure being 0.005592 of a pound, and as a cubic foot equals 28,315,000 cubic millimeters, the probable mass of a molecule of hydrogen will be

$$\frac{0.005592}{32.2\times28{,}315{,}000\times10^{20}}=\frac{11}{18\times10^{29}}\text{ lb.}$$

Maxwell gives $\frac{46}{10^{25}}$ of a gramme$=\frac{3}{7\times10^{28}}$ lb., which is about 3/5 the value given above (*Phil. Mag.* 1873 [4] xlvi p. 468).

The difference in these results arises chiefly from the calculated number of molecules in a cubic foot of gas under ordinary conditions. Thomson gives as the approximate probable number 17×10^{25}, which is about 3/5 the value given by Stoney. Thomson's value would make the mass of a molecule of æther about $\frac{1}{13}\times10^{-40}$ of a pound, which is not much different from that found above.

* The ordinary exponential law results from dropping $\frac{z}{r}$ compared with unity in equation (15), giving

$$\delta=\delta_0\varepsilon^{-\frac{z}{26221}}=\delta_0 10^{-\frac{z\text{ ft.}}{60387}}=\tfrac{1}{4000}\times10^{-\frac{z\text{ miles}}{11.44}},$$

in the last of which, if $z=3956$, the exponent becomes 345.

† *Phil. Mag.* 1873 [4] xlvi. p. 463.

Height.		Density or tension, that at the earth being unity.	Number of molecules in a cubic foot.	Length of the mean free path.
Fractional parts of earth's radius.	Approximate in miles.			
0	0	1	17×10^{35}	2×10^{-6} inch.
$\frac{1}{70}$	50	$10^{-4.3}$	$17\times10^{30.7}$	$2\times10^{-1.7}$ "
$\frac{1}{35}$	100	$10^{-8.4}$	$17\times10^{16.6}$	$2\times10^{2.4}$ "
$\frac{1}{20}$	200	$10^{-16.4}$	$17\times10^{8.6}$	792,000 miles.
$\frac{1}{14}$	282	10^{-23}	17×10^{2}	31×10^{11} "
$\frac{1}{10}$	395	10^{-31}	17×10^{-6}	31×10^{19} "
$\frac{1}{5}$	800	10^{-57}	17×10^{-32}	31×10^{45} "
1	3956	10^{-172}	17×10^{-147}	31×10^{160} "
2	7912	10^{-230}	17×10^{-205}	31×10^{218} "
∞	∞	10^{-345}	17×10^{-320}	31×10^{333} "

æther, we have, by means of equations (11) and (25), substituting in the latter 2116 for $\frac{1}{4000}$,

$$2116\times10^{-345\frac{z}{r+z}}=\frac{4}{10^5},$$

which solved gives

$$z=\frac{r}{31.24}=126.6 \text{ miles},$$

so that at the height of 127 miles the tension would be less than that of the æther, the temperature being uniform.

The mean free path, according to the above law, in which gravity varies as the inverse squares is less, and for great heights much less, than would be found according to the ordinary exponential law. Thus Crookes states that the mean free path of a molecule at the height of 200 miles is about 10,000,000 miles*; but according to the above law it becomes about 792,000 miles.

If a cubic inch of air at sea-level were carried to the height of $\frac{1}{4}$ the radius of the earth, and then allowed to expand freely, so as to become of the computed density of the atmosphere at that point, it would fill a space of $4\times10^{25.12}$ cubic miles, or a sphere whose radius is 2,398,000,000 miles, which is nearly equal to the distance of the planet Neptune from the sun; and there would be less than one molecule to the mile. Such are some of the results of extending a law to extreme cases regardless of physical limitations or of the imperfection of the data on which it is founded. For instance, a uniform temperature is assumed, and, impliedly, an unlimited divisibility of the molecules. The latter is necessary in order to maintain a law of continuity. But modern investigations show that not only air, but all the gases, are composed of molecules of definite magnitudes whose dimensions can be approximately determined; and hence if there be only a few molecules in a cubic foot, and much less if there be but one molecule in a cubic mile, it cannot be claimed that the gas will be governed by the same laws as at the surface of the earth.

To find the Height of the Atmosphere.—The atmosphere will terminate at that height where the vertical repulsive force equals the weight of the particles in the topmost layer. As a first approximation, conceive that the molecules are arranged in horizontal layers and ver-

* "Phil. Trans. Roy. Soc." London, 1881, Part II. p. 389.

tical columns in a prism whose base is one square foot, and whose height extends to the height of the atmosphere; the base of each column of molecules being one of the molecules in the base of the prism. Considering the number of molecules in a cubic foot of air at standard conditions as 17×10^{25}, and the weight of the same as .08 of a pound, we have for the weight of one molecule of air

$$=\frac{8}{17\times10^{27}}* \quad . \quad . \quad . \quad (28)$$

The number of molecules along one edge of the bottom layer will be $\sqrt[3]{17\times10^{25}}$ nearly; and the number in the bottom layer the square of this number or $170\frac{2}{3}\times10^{16}$, which, according to the hypothesis, will be the number in the top layer; and this multiplied by the weight of one molecule will give e, the weight in the top layer; and equation (14) will give (the temperature of the column being considered uniform)

$$14.7\times144\times10^{-345\frac{z}{\tau+z}}=\frac{170\frac{2}{3}\times10^{16}\times8}{17\times10^{27}};$$

$$\therefore \quad z=\frac{\tau}{23.35}=169 \text{ miles}. \quad . \quad (29)$$

But the temperature is far from being uniform. In regard to a definite mass of a gas, we have the well-known relation

$$\frac{e}{\delta\tau}=\frac{e_0}{\delta_0\tau_0}=\text{a constant}=\frac{pv}{\tau}, \quad (29')$$

where $p=e=$the pressure on the base of a prism, and $v=$the volume.

The value of δ from this equation substituted in (13) gives

$$\frac{de}{e}=-g\frac{\delta_0}{e_0}\cdot\frac{\tau_0}{\tau}dz. \quad . \quad . \quad (30)$$

But with τ an unknown variable this cannot be integrated. If $\tau=\tau_0$ we at once have equation(14). The relation between τ and z is unknown, if indeed there be any algebraic relation between them. It is, however, known that, as a general fact, the temperature decreases with the elevation; although local causes and air-currents often cause this law to be rereversed for moderate heights. The best that can be done, in this case, is to find an expression that will represent approximately, the mean values of the temperature. It is usually assumed that the average temperature at the earth is about 59° F. or 60 F., and that for latitudes of, say, 40° N. to 40° S. the perpetual frost-line is from 14,000 to 16,000 feet above sea-level; and observations indicate that the *rate* of decrease of temperature decreases with the height. The last fact is suggestive of an exponential law; hence assuming

$$\tau=\tau_0\varepsilon^{-\frac{z}{a}}, \quad . \quad . \quad . \quad (31)$$

and making $\tau=493°$ F., absolute, at the height $z=15{,}840$ feet and $\tau_0=520°$ F., absolute, we find $a=296{,}000$ (or 56 if z be in miles), and our equation becomes

$$\tau=520\varepsilon^{-\frac{z \text{ miles}}{56}} \quad . \quad . \quad . \quad (3\cdot)$$

This gives

Height, miles.	τ absolute.	Fahr. scale.	Glaisher's observa tions.*
0	520° F.	59° F.	59° F.
1–5	518	57	..
2–5	515	54	..
3–5	513	52	..
4–5	512	51	..
1	510	49	41
2	501	40	32
3	493	32	18
4	484	23	8
5	475	14	— 2
6	467	6	..
7	458	— 3	—11.8
50	212	—249	..
75	136	—325	..
100	87	—374	..
120	65	—396	..
150	36	—425	..
224	9	—452	..

The temperatures given in twenty-five or more reports of balloon ascensions, not only give values the mean of which is fairly represented by the celebrated seven-mile ascent of Mr. Glaisher, but his

* This may be used as a unit for measuring the mass of a cubic foot of the æther. Thus, dividing the value in equation (10) by that in (28) gives 4250; or the mass of æther in a cubic foot is 4250 times the mass of one molecule of air.

* "Travels in the Air," by James Glaisher, F. R. S. p. 50.

figures, given in the fourth column of the table, represent a more uniform law than is common in such reports. Our computed values exceed his observed values at all points except at the surface of the earth, where they agree. In this ascent he reached the point of freezing at the height of two miles, which is lower than the average, as determined by many observations; and, therefore, it appears that equation (31) probably represents the general law better than this single set of observations. The effect, however, of the exponential law is scarcely perceptible within the limits of observation; for the exponent of ϵ is so small for elevations under seven miles, that it makes the law of decrease of temperature nearly uniform with equal increments of elevation. Thus, omitting fractions, the computed decrease for the first mile is 10°, and the average for seven miles is nearly 9°; but to assume a uniform decrease throughout the column limits its height independently of pressure or other conditions, for it could not extend beyond the point of absolute zero. There is no objection to applying such a law, provided it can be shown to be true—a condition which, at present, is not accepted.

Substituting τ from (31) in (30), and integrating between the limits of z and $z=0$, gives

$$e=e_0\,\epsilon^{-\frac{ag\delta_0}{e_0}\left(\epsilon^{\frac{z}{a}}-\right.}\quad;\quad\ldots\quad(33)$$

which ultimately will equal the weight of the molecules in the top layer. Hence, substituting numbers, we have

$$2116=\frac{8\times 170^{\frac{3}{3}}\times 10^{16}}{17\times 10^{27}}\,\epsilon^{\frac{296000\times.08}{2116}\left(\epsilon^{\frac{z}{56}}-1\right)};$$

which gives

$$e=86 \text{ miles.}\quad\ldots\quad(34)$$

It is evident that the hypothetical column of uniform temperature will be very much shortened by the very low temperature of the higher regions; but there are other conditions which will modify the preceding analysis. The assumptions in regard to layers and columns would not be realized even under statical conditions, and much less for the conditions in nature. Statically, the molecules would arrange themselves more like shot in a pile, each being over the space between the molecules in the layer below, instead of being directly over a molecule. This arrangement would give a less number in the horizontal layers than assumed above. But the hypothesis of constancy in the number of molecules in the layers is open to greater objections. For the distance between them will increase with the elevation on account of the diminution of the pressure of that part of the column above the point considered, and the elastic force will be correspondingly diminished; while, horizontally, in the plane of a layer of the molecules, the elastic force would remain constant. In other words, in the medium arranged as assumed the tension would not be the same in all directions, and hence would be in unstable equilibrium. As a refinement, we notice that in every heavy fluid the downward pressure at every point exceeds the upward by the weight of a molecule.

Considering, now, that the molecules in the hypothetical layers are distributed uniformly throughout the spaces immediately beneath them, the number in the new top layer will be less than in the former case, and the column will rise to a greater height, and hence will exceed 86 miles; and, in turn, the new column would need another correction, and so on. Assuming that the number in the top layer is 10^{16}, and that the vertical component of the elastic forces follows the law of equation (33), we find

$$z=95 \text{ miles};$$

and if the number in the top layer be 10^4, we find $z=104$ miles, and for *one* molecule, $z=110$ miles. In a similar manner it would be legitimate to assume that the column was capped by a fraction of a molecule, for that would be equivalent to one molecule at the top of a column having a base of several square feet. We are unable to determine where this process would end in nature; and hence this analysis fails to fix definitely the extreme height of the atmosphere, even for statical conditions.

Assuming that the distance between

the contiguous molecules would be inversely as the third root of the densities of the medium, as they would be with sufficient accuracy where the number of molecules in a cubic foot is immense, we have, after substituting e, equation (33), and τ, equation (31), in (29′),

$$\frac{\delta}{\delta_s}=\varepsilon\left(\frac{z}{a}-\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}}-1\right)\right)=\frac{d_0^3}{d^3},$$

where d_0 is the distance between contiguous molecules at sea-level and d the corresponding distance at the height z. Hence

$$d=d_0\left(\varepsilon^{\frac{ag\delta_0}{e_0}\left(\varepsilon^{\frac{z}{a}}-1\right)-\frac{z}{a}}\right)^{\frac{1}{3}} \quad . \quad . \quad (35)$$

If $d_0=\frac{18}{\sqrt[3]{170\times10^8}}$, $\frac{ag\delta_0}{e_0}=11.19$; we have

for $z=$ 86 miles, $d=\frac{1}{95}$ of an inch,
" $z=$ 95 " $d=$ 4.5 inches,
" $z=$104 " $d=$11.4 "

These values of d are greatly in excess of the distances between contiguous molecules in the horizontal layers, according to assumed conditions. Thus, at the height of 104 miles, it was *assumed* that there were 10^8 molecules on the side of a square foot, in which case the distance between contiguous molecules would be about $\frac{1}{5}$ of an inch instead of 11 inches as above. These results ought not to agree exactly, for one analysis assumes that the atmosphere terminates with each assumed number of molecules, while the other assumes that the law is continuous to any height. It is apparent that the laws represented by equations (33) and (35) both become practically discontinuous at a height at or less than 95 miles. For the sake of giving definiteness to the following remarks, we will assume that the mean height for statical conditions is 95 miles. But the conditions in nature are not statical. The changes in temperature in the column will be continually increasing or decreasing its height: the air-currents also operate to change it, first by increasing or decreasing the temperature from the mean at considerable heights, and, secondly, by operating dynamically to push the top of the column upward; the aerial tides may operate to raise the column still higher, and the molecules themselves are supposed to be flying with great rapidity in all directions. An increase of temperature of one-tenth the mean value, which, at the earth's surface would be about 49° F., would elongate the column about ten miles, and a corresponding decrease would shorten it about the same amount, making it 105 miles in the former case and 85 miles in the latter. The effect of air-currents and aerial tides cannot be so definitely calculated; but it is safe to assume that they may produce a much greater increase of height above the mean than they will depression below the mean; just as in a highly agitated sea, the depressions below the mean surface-level may be small compared with the height above the same level to which the spray from the top of a wave may be thrown. It seems possible, therefore, that when the temperature, air-currents, and aerial tides conspire to depress the column, the extreme height of the atmosphere may be reduced to less than 85 miles; and when they conspire to elevate it, it may possibly rise to a height exceeding 120 miles.

If it be certain, as is assumed, that meteors are rendered incandescent by atmospheric friction, and the extreme height at which they are visible could be determined by direct observation, it would fix a height less than the extreme height of the atmosphere, independent of other physical considerations; but the movement of these bodies is so extremely rapid that it is impossible to determine their height with astronomical precision. Still, computations by Professor Herschel give a height of about 118 miles,* and Professor Newcomb estimates it to be about 100 miles.† It is possible that a meteor would sometimes become inflamed by penetrating the atmosphere only a few miles, for although the atmosphere in

* Professor A. S. Herschel gives the height of 20 meteors varying from 40 to 118 miles.—*Nature*, vol. iv. p. 504.

† Newcomb says: "The lightning-like rapidity with which the meteors darted through their course rendered it impossible to observe them with astronomical precision; but the general result was that they were first seen at an average height of 75 miles and disappeared at a height of 55 miles. There was no positive evidence that any meteor commenced at a height greater than 100 miles. These phenomena seem to indicate that our atmosphere really extends to a height of 100 and 110 miles."—"Popular Astronomy," 1878, p. 389.

the upper regions is extremely rare, yet the actual number of molecules in a cubic foot is large. Thus, according to our analysis, for statical conditions, the topmost cubic foot of the 104-mile column would contain about 1,000,000 molecules; and at the height of 95 miles it would contain about 1,000,000,000,000,000 molecules; so that if the relative velocities of the meteor and air be 20 miles per second, the meteor would encounter an *enormous* number in the twentieth or even the hundredth part of a second, after first entering the atmosphere.

The height of the auroral arch—supposed to be within our atmosphere—has been computed to be from 33 to 1,000 miles (see article *Aurora*, "Encyclopœdia Britannica"). But it has been shown by experiment, that a vacuum may be produced through which an electrical discharge cannot be passed, and yet the atmosphere at the height of 150 miles under the most favorable condition, that of uniform temperature, is vastly more rare than the most perfect vacuum ever produced by the most perfect Sprengel pump; and at the height of 200 miles under the same conditions the vacuum would be some 10,000,000 times as great as the most perfect vacuum yet made; while, according to the probable law of the decrease of temperature with the elevation, and in accordance with the probable mass of a molecule of air, the extreme height falls far short of 150 miles. It is evident, therefore, that the assumed determination of the height of the atmosphere by means of the auroral arch is, to say the least, unreliable.*

We have pursued this digression in regard to the atmosphere partly for its own sake and partly to show, by way of contrast and accumulative evidence, that the æther is a substance entirely distinct from that of the atmosphere,—that the former cannot be considered as the latter greatly rarefied, as some have supposed. Admitting the validity of the preceding discussion, some of the distinctive properties are:

1. The different modes of the movements of the molecules in the two substances in the propagation of a wave; in one the motion being a to-and-fro movement and in the other a transverse movemovement. These are distinctions recognized by the best writers upon the subject, and are especially noticed by Maxwell in an article on *Ether* in the "Encyclopœdia Britannica."

2. It is impossible for a wave to be transmitted in air with the known velocity of light, unless its temperature be increased millions of millions of degrees Fahrenheit above the standard temperature; but such a wave is transmitted in the æther although its temperature is far less than has ever been produced by artificial means.

3. The ratio of the elasticity to the density in the æther is exceedingly large compared with the same ratio in air. The temperature of air being taken at 60° F., and the æther at 20° F., absolute, the ratio is, with sufficient accuracy,

$$\left(\frac{980{,}000{,}000}{1{,}090}\right)^2 = 8\times 10^{11}.$$

4. The specific heat of the æther is, at least, many million times that of air, or of any other known gas.

5. The atmosphere is of variable density, elasticity, and temperature, while the æther is well-nigh isometric throughout space in regard to each of these elements.

6. A molecule of æther is well-nigh infinitesimal compared with one of air.

7. Air is attracted to a planet with such a relative force, that its extreme height is only a few miles.

8. The ratio of the density to the elasticity of the æther is constant; but in the atmosphere, on account of the decrease of temperature with the elevation, the density decreases less rapidly than the elasticity, as may be seen by comparing the first part of equation (35) with equation (33), we have

$$\frac{\delta}{\delta_0} = \varepsilon^{\frac{z}{a}} \cdot \frac{\varrho}{\varrho_0}.$$

On this account a wave would be propagated with less velocity in the higher regions of the atmosphere than in the lower, while a wave in the æther has a sensibly uniform velocity throughout space.

The question may arise, May not the resistance of the æther drag away the re-

* Some writers incline to the view that the aurora is due to a cosmic rather than a terrestrial origin.—*Science*, 1885, p. 395.

mote molecules of the atmosphere, and so scatter them in space along the path of the earth's orbit? Assuming that the atmosphere is moving with the earth through space at the rate of 20 miles per second (which exceeds the actual velocity), and that the resistance of the æther is measured in the same manner as for fluids, we have for the resistance

$$R=kwa\frac{v^2}{2g},$$

where v is the velocity of a molecule of air a its meridian section, w the weight of a unit of volume of the æther, and k a coefficient depending upon the form of the body. Making $k=1$, which is greater than its actual value, and $a=\frac{1}{10^{17}}$ feet, which, again, is in excess of the true area, w the value in equation (10), we find that

$$R=\frac{2}{10^{44}}\times\frac{1}{10^{17}}\times(20\times5{,}280)^2.$$

$$\frac{1}{64.4}=\frac{1}{10^{33}}\text{ of a pound nearly.}$$

The attractive force of the earth for a molecule of air is given in equation (28), and hence the attraction of the earth for a molecule of air will exceed 500,000 times the resistance of the æther; hence the molecules of air accompany the earth in its orbit as certainly as does the moon, and are more rigidly bound to it than is its satellite.

The kinetic energy of a molecule of air at standard conditions is about

$$\frac{1}{2}\cdot\frac{8}{32.2\times17\times10^{27}}1{,}600^2=\frac{2}{10^{23}}\text{ foot-pound;}$$

and of the æther, according to our results, about

$$\frac{1}{2}\cdot\frac{1}{22\times10^{10}}(273{,}000\times5{,}280)^2=\frac{1}{2\times10^{23}}\text{ foot-pound;}$$

which results are nearly the same; but in a pound of the æther there is some 100,000,000,000 times the kinetic energy of a pound of air.

Considering the terrestrial atmosphere as equivalent to one of uniform density and 5½ miles high, each of whose molecules has a mean square velocity of 1,600 feet per second, and the æther of uniform density, each of whose molecules has the mean square velocity of 286,000 miles per second, a rough approximation shows that the kinetic energy of the æther in a sphere whose radius is 92,000,000 miles (nearly the distance of the earth from the sun) will be only about 100,000 times that in our atmosphere.

The mean free path of a molecule of gas, as given by Loschmidt, is

$$l=\frac{\text{combined volume of the molecules}}{\text{volume of the gas}\times\frac{1}{8}\text{ the diameter of a molecule}},$$

and by Maxwell,

$$l=\frac{\mu}{\rho}\cdot\frac{1}{v}=3\frac{\mu}{\rho}\cdot\frac{z}{\gamma V};$$

(the last member of which we have added), in which ρ is the density of the gas, μ the coefficient of internal friction, and v the velocity whose square is the mean of the squares of the actual velocities of the molecules. In regard to the æther, these equations contain at least three unknown quantities, l, μ, and the diameter of a molecule, and hence they cannot be completely solved. Comparative results, however, may be found by assuming that the density of the molecules of æther equals those of hydrogen, or is any multiple thereof; for then the diameter of a molecule of the æther might be found (that of hydrogen being 5.6×10^{-10} of a meter); and the combined volume in a cubic foot will equal the number of molecules in a cubic foot multiplied by the volume of one molecule, and hence will be found the length of the mean free path and the coefficient of internal friction.

We conclude, then, that a medium whose density is such that a volume of it equal to about twenty volumes of the earth would weigh one pound, and whose tension is such that the pressure on a square mile would be about one pound, and whose specific heat is such that it would require as much heat to raise the temperature of one pound of it 1° F. as it would to raise about 2,300,000,000 tons of water the same amount, will satisfy the requirements of nature in being able to transmit a wave of light or heat 186,300 miles per second, and transmit 133 foot-pounds of heat-energy from the

sun to the earth each second per square foot of surface normally exposed, and also be everywhere practically non-resisting and sensibly uniform in temperature, density and elasticity. This medium we call the Luminiferous Æther.

THE SURVEY OF INDIA.

By General J. T. WALKER, C. B., LL. D., F. R. S.

Abstract of Address before Geographical Section of British Association.

Scientific geography embraces a wide range of subjects, wider than can be claimed for any other department of science. Thus the president of this Section has a vast field from which to gather subjects for his opening address. I shall, however, restrict my address to the subject with which I am most familiar, and give you some account of the survey of India, and more particularly of the labors of the trigonometrical or geodetic branch of that survey, in which the best years of my life have been passed.

I must begin by pointing out that the survey operations of India have been very varied in nature, and constitute a blending together of many diverse ingredients. Their origin was purely European, nothing in the shape of a general survey having been executed under the previous Asiatic governments; lands had been measured in certain localities, but merely with a view to acquiring some idea of the relative areas of properties, in assessing on individuals the share of the revenue levied on a community; but other factors than area—such as richness or poverty of soil, and proximity or absence of water—influenced the assessment, and often in a greater degree, so that very exact measurements of area were not wanted for revenue purposes, and no other reason then suggested itself why lands should be accurately measured. The value of accurate maps of individual properties, with every boundary clearly and exactly laid down, was not thought of in India in those days, and indeed has only of late years begun to be recognized by even the British Government. The idea of a general geographical survey never suggested itself to the Asiatic mind. Thus, when Englishmen came to settle in India, one of their first acts was to make surveys of the tracts of country over which their influence was extending, and as that influence increased, so the survey became developed from a rude and rapid primary delineation of the broad facts of general geography, to an elaborately executed and artistic delineation of the topography of the country, and in some provinces to the mapping of every field and individual property. Thus there have been three orders or classes of survey, and these may be respectively designated geographical, topographical, and cadastral; all three have frequently been carried on *pari passu*, but in different regions, demanding more or less elaborate survey, according as they happened to be more or less under British influence. There is also the Great Trigonometrical or Geodetic Survey, by which the graphical surveys are controlled, collated, and coordinated, as I will presently explain.

Survey operations in India began along the coast lines before the commencement of the seventeenth century, the sailors preceding the land surveyors by upwards of a century. The Directors of the East India Company, recognizing the importance of correct geographical information for their mercantile enterprises, appointed Richard Hakluyt, Archdeacon of Westminster, their historiographer and custodian of the journals of East Indian voyages, in the year 1601, within a few weeks of the establishment of the company by royal charter. Hakluyt gave lectures to the students at Oxford, and is said by Fuller to have been the first to exhibit the old and imperfect maps and the new and revised maps for comparison in the common schools, "to the singular pleasure and great contentment of his auditory." The first general map of India was published in 1752 by the celebrated French Geographer D'Anville, and was a meritorious compilation from the existing charts of coast lines and itineraries of travelers.

But the Father of Indian Geography, as he has been called, was Major Rennel, who landed in India as a midshipman of the Royal Navy in 1760, distinguished himself in the blockade of Pondicherry, was employed for a time in making surveys of the coast between the Paumben Passage and Calcutta, was appointed Surveyor of the East India Company's dominions in Bengal in 1764, was one of the first officers to receive a commission in the Bengal Engineers on its formation, and in 1767 was raised to the position of Surveyor-General. Bengal was not in those days the tranquil country we have known it for so many years, but was infested by numerous bands of brigands who professed to be religious devotees, and with whom Rennel came into collision in the course of one of his surveying expeditions, and was desperately wounded; he had to be taken 300 miles in an open boat for medical assistance, the natives meanwhile applying onions to his wounds as a cataplasm. His labors in the survey of Bengal lasted over a period of nineteen years, and embraced an area of about 300,000 square miles, extending from the eastern boundaries of Lower Bengal to Agra, and from the Himalayas to the borders of Bandelkand and Chota Nagpur. Ill health then compelled him to retire from the service on a small pension and return to England; but not caring, as he said, to eat the bread of idleness, he immediately set himself to the utilization of the large mass of geographical materials laid up and perishing in what was then called the India House; he published numerous charts and maps, and eventually brought out his great work on Indian Geography, the "Memoir of a Map of Hindostan," which went through several editions; this was followed by his Geographical System of Herodotus, and various other works of interest and importance. His labors in England extended over a period of thirty-five years, and their great merits have been universally acknowledged.

Rennell's system of field work in Bengal was a survey of routes checked and combined by astronomical determinations of the latitude and the longitude, and a similar system was adopted in all other parts of India until the commencement of the present century. But in course of time the astronomical basis was found to be inadequate to the requirements of a general survey of all India, as the errors in the astronomical observations were liable materially to exceed those of the survey, if executed with fairly good instruments and moderate care. Now this was no new discovery, for already early in the eighteenth century the French Jesuits who were making a survey of China, with the hope of securing the protection of the Emperor, which they considered necessary to favor the progress of Christianity, had deliberately aban doned the astronomical method and em ployed triangulation instead. Writing in the name of the missionaries who were associated with him in the survey, Père Regis enters fully into the relative advantages of the two methods, and gives the trigonometrical the preference, as best suited to enable the work to be executed in a manner worthy the trust reposed in them by a wise prince, who judged it as of the greatest importance to his State. "Thus," he says, "we flatter ourselves we have followed the surest course, and even the only one practicable in prosecuting the greatest geographical work that was ever performed according to the rules of art."

What was true in those days is true still; points whose relative positions have been fixed by any triangulation of moderate accuracy present a more satisfactory and reliable basis for topographical survey than points fixed astronomically. Though the lunar theory has been greatly developed since those days by the labors of eminent mathematicians, and the accuracy of the lunar tables and star catalogues is much increased, absolute longitudes are still not susceptible of ready determination with great exactitude; moreover, all astronomical observations, whether of latitude or longitude, are liable to other than intrinsic errors, which arise from deflection of the plumb-line under the influence of local attractions, and which of themselves materially exceed the errors that would be generated in any fairly executed triangulation of a not excessive length, say not exceeding 500 miles.

Thus at the close of the last century Major Lambton, of the 33d Regiment, drew up a project for a general triangulation of Southern India. It was strongly supported by his commanding officer,

Colonel Wellesley, afterwards the Duke of Wellington, and was readily sanctioned by the Madras Government; for a large accession of territory in the center of the peninsula had been recently acquired, as the result of the Mysore campaign, by which free communication had been opened between the east and west coasts of Coromandel and Malabar, and the proposed triangulation would not merely furnish a basis for new surveys, but connect together various isolated surveys which had already been completed or were then in progress. The Great Trigonometrical Survey of India owes its origin as such, and its simultaneous inception as a geodetic survey, to Major Lambton, who pointed out that the trigonometrical stations must needs have their latitudes and longitudes determined for future reference just as the discarded astronomical stations, not, however, by direct observation, but by processes of calculation requiring a knowledge of the earth's figure and dimensions. But at that time the elements of the earth's figure were not known with much exactitude, for all the best geodetic arcs had been measured in high latitudes, the single short and somewhat questionable arc of Peru being the only one situated in the vicinity of the equator. Thus additional arcs in low latitudes, as those of India, were greatly needed and might be furnished by Lambton. He took care to set this forth very distinctly in the programme which he drew up for the consideration of the Madras Government, remarking that there was thus something still left as a desideratum for the science of geodesty, which his operations might supply, and that he would rejoice indeed should it come within his province "to make observations tending to elucidate so sublime a subject."

Lambton commenced operations by measuring a base line and a small meridional arc near Madras, and then, casting a set of triangles over the southern peninsula, he converted the triangles on the central meridian into a portion of what is now known as the Great Arc of India, measuring its angles with extreme care, and checking the triangulation by base lines measured at distances of two to three degrees apart in latitude. His principal instruments were a steel measuring chain, a great theodolite, and a zenith sector, each of which had a history of its own before coming into his hands. The chain and zenith sector were sent from England with Lord Macartney's Embassy to the Emperor of China, as gifts for presentation to that potentate, who, unfortunately, did not appreciate their value and declined to accept them; they were then made over to Doctor Dinwiddie, the astronomer to the embassy, who took them to India for sale. The theodolite was constructed in England for Lambton, on the model of one in use on the Ordnance Survey; on its passage to India it was captured by the French frigate, the *Piemontaise*, and landed at Mauritius, but eventually it was forwarded to its destination by the chivalrous French Governor, De Caen, with a complimentary letter to the Governor of Madras.

Lambton was assisted for a short time by Captain Kater, whose name is now best known in connection with pendulum experiments and the employment of the seconds pendulum as a standard of length, but for many years afterwards he had no officer to assist him. At first he met with much opposition from advocates of the discarded astronomical method, who insisted on its being sufficiently accurate and more economical than the trigonometrical. But he was warmly supported by Maskelyne, the Astronomer-Royal in England, and soon had an opportunity of demonstrating the astronomical method to be fallacious, for its determination of the breadth of the peninsula in the latitude of Madras was proved by the triangulation to be forty miles in error. Still, for several years he never received a word of sympathy, encouragement, or advice either from the Government or from the Royal Society. A foreign nation was the first to recognize the importance of his services to science, the French Institute electing him a corresponding member in 1817. After this, honors and applause quickly followed from his own countrymen. In 1818 the Governor-General of India, then the Marquis of Hastings, decided that the survey should be withdrawn from the supervision of a local Government and placed under the Supreme Government, with a view to its extension over all India, remarking at the same time that he was "not aware that with minds of a certain

order he might lay himself open to the idle imputation of vainly seeking to partake of the gale of public favor and applause which the labors of Colonel Lambton had recently attracted;" but as the survey had reached the northern limits of the Madras Presidency, its transfer to the Supreme Government, if it was to be further extended, had become a necessity. He directed the transfer to be made, and the survey to be called in future the Great Trigonometrical Survey of India. Noticing that the intense mental and bodily labor of conducting it was being performed by Lambton alone, that his rank and advancing age demanded some relief from such severe fatigue, and further that it was not right that an undertaking of such importance should hang on the life of a single individual, the Governor-General appointed two officers to assist him, Captain Everest, as chief assistant in the geodetic operations, and Dr. Voysey, as surgeon and geologist. Five years afterwards Lambton died, at the age of seventy. The happy possessor of an unusually robust and energetic constitution and a genial temperament, he seems to have scarcely known a day's illness, though he never spared himself nor shrank from subjecting himself to privations and exposure which even Everest thought reckless and unjustifiable. These he accepted as a matter of course, saying little about them, and devoting his life calmly and unostentatiously to the interests of science and the service of his country.

Everest's career in the survey commenced disastrously. He was deputed by Lambton to carry a triangulation from Hyderabad, in the Nizam's territory, eastward to the coast, crossing the forest-clad and fever-haunted basin of the Godavery river, a region which he described as "a dreadful wilderness, than which no part of the earth was more dreary, desolate, and fatal." Indignant at being taken there, his escort, a detachment of the Nizam's troops, mutinied, and soon afterwards he and his assistants and almost all the men of his native establishment were stricken down by a malignant fever; many died on the spot, and the survivors had to be carried into Hyderabad, whence litters and vehicles of all descriptions, and the whole of the public elephants, were dispatched to their succor. To recover his health Everest was compelled to leave India for a while and proceed to the Cape of Good Hope, where he remained for three years. He availed himself of the opportunity to inspect Lacaille's meridional arc, which, when compared with the arcs north of the equator, indicated that the opposite hemispheres of the globe were seemingly of different ellipticities. He succeeded in tracing this anomaly to an error in the astronomical amplitude of the arc, which had been caused by deflection of the plumb-line at the ends of the arc, under the influence of the attraction of neighboring mountains. Thus he became aware of the necessity of placing the astronomical stations of the Indian arcs at points where the plumb-line would not be liable to material deflection by the attraction of neighboring mountain ranges. Shortly after his return to India Lambton died, and Everest succeeded him, and immediately concentrated his energies on the extension of the Great Arc northwards. He soon came to the conclusion that his instrumental equipment, though good for the time when it was procured, and amply sufficient for ordinary geographical purposes, was inadequate for the requirements of geodesy, and generally inferior to the equipments of the geodetic surveys then in progress in Europe. He therefore proceeded to Europe to study the procedure of the English and French surveys, and also to obtain a supply of new instruments of the latest and most improved forms. The Court of Directors of the Honorable East India Company accorded a most liberal assent to all his proposals, and gave him *carte blanche* to provide himself with whatever he considered desirable to satisfy all the requirements of science.

Everest returned to India with his new instrumental equipment in 1830, a year that marks the transition of the character of the operations from an order of accuracy which was sufficient as a basis for the graphical delineation of a comparatively small portion of the earth's surface, to the higher precision and refinement which modern geodesists have deemed essentially necessary for the determination of the figure and dimensions of the earth as a whole. He immediately introduced an important modification of

the general design of the principal triangulation, which up to that time had been thrown as a network over the country on either side of the Great Arc, as in the English survey and many others; but he abandoned this method, and, adopting that of the French survey instead, he devised a system of meridional chains to be carried at intervals of about 1° apart, and tied together by longitudinal chains at intervals of about 5°, the whole forming, from its resemblance to the homely culinary utensil with which we are all familiar, what has been called the gridiron system in contradistinction to the network. The entire triangulation was to rest on base lines to be measured with the new Colby apparatus of compensation bars and microscopes which had been constructed to supersede the measuring chain the Emperor of China had rejected; the base lines were to be placed at the intersections of the longitudinal chains of triangles with the central meridional or axial chain, and also at the further angles of the gridirons on each side. Latitudes were to be measured at certain of the stations of the central chain, with new astronomical circles in place of the old zenith sector, to give the required meridional arcs of amplitude. Two radical improvements on all previous procedure were introduced in the measurement of the principal angles, one affecting the observations, the other the objects observed. The great theodolites were manipulated in such a manner as not merely to reduce the effects of accidental errors by numerous repititions in the usual way, but absolutely to eliminate all periodic errors of graduation by systematic changes of the position of the azimuthal circle relatively to the telescope, in the course of the complete series of measures of every angle. The objects formerly observed had been cairns of stones or other opaque signals; for these Everest substituted luminous signals, lamps by night, and, by day, heliotropes which were manipulated to reflect the sun's rays through diaphragms of small aperture, in pencils appearing like bright stars, and capable of penetrating a dense atmosphere through which distant opaque objects could not be seen.

Everest's programme of procedure furnished the guiding principles on which the operations were carried out during the period of half a century which intervened between their commencement under his superintendence and the completion of the principal triangulation under myself. The external chains have necessarily been taken along the winding course of the frontier and coast lines, instead of the direct and more symmetrical lines of the meridians and the parallels of latitude. The number of the internal meridional chains has latterly been diminished by widening the spaces between them, and in two instances a principal chain has been dispensed with, because, before it could be taken in hand, a good secondary triangulation had been carried over the area for which it was intended to provide. But these are departures from the letter rather than the spirit of Everest's programme which has been faithfully followed throughout, first by his immediate successor, Sir Andrew Waugh, and afterwards by myself, thus affording an instance of the impress of a single mind on the work of half a century, which is probably unique in the annals of India, for here, as is well known, changes of personal administration are frequent, and are not uncommonly followed by changes of procedure.

The physical features of a country necessarily exercise a considerable influence on the operations of any survey that may be carried over it, and more particularly on those of a geodetic survey, of which no portion is allowed to fall below a certain standard of precision. Every variety of feature, of scenery, and of climate that is to be met with anywhere on the earth's surface between the equator and the arctic regions has its analogue between the highlands of Central Asia and the ocean, which define the limits of the area covered by the Indian survey. Thus in some parts the operations were accomplished with ease, celerity, and enjoyment, while in others they were very difficult and slow of progress, always entailing great exposure, and at times very deadly. In an open country, dotted with hills and commanding eminences, they advanced as on velvet; in close country, forest-clad, or covered with other obstacles to distant vision, they were greatly retarded, for there it became necessary either to raise the stations to a sufficient height to overlook all surrounding ob-

stacles, or to render them mutually visible by clearing the lines between them, and both these processes are more or less tedious and costly. There are many tracts of forest and jungle which greatly impeded the operations, not merely because of the physical difficulties they presented, but because they teemed with malaria, and were very deadly during the greater portion of the year, and more particularly immediately after the rainy season, when the atmosphere is usually clearest and most favorable for distant observations. At first tracts of forest, covering extensive plains, were considered impracticable; thus Lambton carried his network over the open country, and stopped it whenever it reached a great plain covered with forest and devoid of hills; but Everest's system would not permit of any break of continuity, nor the abandonment of any chain which was required to complete a gridiron; it has been carried out in all its integrity, often with much sacrifice of life, but never with any shrinking on the part of the survey officers from carrying out what it had become a point of honor with them to accomplish, and the accomplishment of which the Government had come to regard as a matter of course. We have already seen how the progress of Everest's first chain of triangles was suddenly arrested because he and all his people were struck down by malaria in the pestilential regions of the Godavery basin. That chain remained untouched for fifty years; it was then resumed and completed, but with the loss of the executive officer, Mr. George Shelverton, who succumbed when he had not yet reached, but was within sight of, the east coast line, the goal toward which his labors were directed. Many regions, as the basin of the Mahanaddi, the valley of Assam, the hill ranges of Tipperah, Chittagong, Arracan, and Burma, and those to the east of Moulmein and Tennasserim, which form the boundary between the British and the Siamese territories, are covered with dense forest, up to the summits of the peaks which had to be adopted as the sites of the survey stations. As a rule the peaks were far from the nearest habitation, and they could not be reached until pathways to them had been cut through forests tangled with a dense undergrowth of tropical jungle; not unfrequently large areas had to be cleared on the summits to open out the view of the surrounding country. Here the physical difficulties to be overcome were very considerable, and they were increased by the necessity that arose, in almost every instance, of importing laborers from a great distance to perform the necessary clearances. But the broad belt of forest tract known as the Terai, which is situated in the plains at the feet of the Nepalese Himalayas, was the most formidable region of all, because the climate was very deadly for a great portion of the year, and more particularly during the season when the atmosphere was most favorable for the observations, though the physical difficulties were not so great as in the hill tracts just mentioned, and labor was more easily procurable. Lying on the British frontier, at the northern extremities of no less than ten of the meridional chains of triangles, it had necessarily to be operated in to some extent, and Everest wished to carry the several chains across it, on to the outer Himalayan range, and then to connect them together by a longitudinal chain running along the range from east to west, completing the gridiron in this quarter. But the range was a portion of the Nepalese territories, and all Europeans—excepting those attached to the British embassy at Khatmandu—were debarred from entering any part of Nepal, by treaty with the British Government. Everest hoped that the rulers of Nepal might make an exception in his favor for the prosecution of a scientific survey; and when he found they would not, he urged the Government to compel them to give his surveyors access, at least, to their outlying hills; but he urged in vain, for the Government would not run the risk of embarking in a war with Nepal for purely scientific purposes. Thus the connecting chain of triangles—now known as the N. E. Longitudinal Series—had to be carried through the whole length of the Terai, a distance of about 500 miles, which involved the construction of over 100 towers, raised to a height of about 30 feet to overlook the earth's curvature, and the clearance of about 2,000 miles of line through forest and jungle to render the towers mutually visible. It required no small courage on Everest's part to plunge his surveyors

into this region; he endeavored to minimize the risks as much as possible by taking up the longitudinal chain in sections, bit by bit, on the completion of the successive meridional chains, and thus apportioning it between several survey parties, each operating in the Terai for a short time, instead of assigning it to a single party to execute continuously from end to end, as all the other chains of triangles. But notwithstanding these precautions, the peril was great, and the mortality among both officers and men was very considerable; greater than in many a famous battle, says Mr. Clements Markham, in an eloquent passage in his Memoir of the Indian Surveys, in which he claims for the surveyors who were employed on these operations—with no hope of reward other than the favorable notice of their immediate chief and colleagues—merit for more perilous and honorable achievement than much of the military service which is plentifully rewarded by the praises of men and prizes of all kinds.

Everest retired in 1843, and was succeeded by Waugh, who applied himself energetically to the completion of the several chains of triangles exterior to the Great Arc, for which he obtained a substantial addition to the existing equipment of great theodolites. It was under him that the formidable longitudinal series, through the Terai, which had been begun by Everest, was chiefly carried out. He personally initiated the determination of the positions and heights of the principal snow peaks of the Himalayan ranges; and he did much for the advancement of the general topography of India, which had somewhat languished under his predecessor, who had devoted himself chiefly to the geodetic operations. He retired in 1861, and I succeeded to the charge of the Great Trigonometrical Survey. The last chain of the principal triangulation was completed in 1882, shortly before my own retirement.

On the general character of the operations, it may be asserted without hesitation that a degree of accuracy and precision has been attained which has been reached by few and surpassed by none of the great national surveys carried out in other parts of the world, and which leaves nothing to be desired even for the requirements of geodesy; a very considerable majority of the principal angles have been measured with the great 24-inch and 36-inch theodolite, and their theoretical probable error averages about a quarter of a second; of the linear measurements the probable error, so far as calculable may be taken as not exceeding the two-millionth part of any measured length. And as regards the extent of the triangulation, if we ignore the primary network in Southern India, and all secondary triangulation, however valuable for geographical purposes, we still have a number of principal chains—meridional, longitudinal, and oblique—of which the aggregate length is 17,300 miles, which contain 9,230 first-class angles all observed, and rest on 11 base lines measured with the Colby apparatus of compensation bars and microscopes. This prodigious amount of field work furnishes an enormous mass of interdependent angular and linear measures, and each of these is fallible in some degree, for, great as was the accuracy and care with which they had severally been executed, perfect accuracy of measurement is as yet beyond human achievement; thus every circuit of triangles, every chain closing on a base line, and even every single triangle, presented discrepancies the magnitude of which was greater or less according as derived from a combination of many, or only of a few, of the fallible facts of observation. Thus, when the field operations were approaching their termination, the question arose as to how these facts were to be harmonized and rendered consistent throughout, which was a very serious matter considering their great number. The strict application of mathematical theory to a problem of this nature requires the adjustment to be effected by the application of a correction to every fact of observation, not arbitrarily, but in such a manner as to give it its proper weight, neither more nor less, in the final investigation, and in this the whole of the facts must be treated simultaneously. That would have involved the simultaneous solution of upwards of 4,000 equations between 9,230 unknown quantities, by what is called the method of minimum squares, and I need scarcely say that it is practically impossible to solve such a number of equations between so many unknown quantities by any method at

all. Thus a compromise had to be made between the theoretically desirable and the practically possible. It would be out of place here to attempt to describe the method of treatment which was eventually adopted, after much thought and deliberation; I will merely say that the bulk of the triangulation was divided into five sections, each of which was treated in succession with as close approximation to the mathematically rigorous method as was practically possible; but even then the mass of simultaneous interdependent calculation to be performed in each instance was enormous, I believe greatly exceeding anything of the kind as yet attempted in any other survey. But the happy result of all this labor was that the final corrections of the angles were for the most part very minute, less than the theoretical probable errors of the angles, and thus fairly applicable without taking any liberties with the facts of observation. If the attribute of beauty may ever be bestowed on such things as small numerical quantities, it may surely be accorded to these notable results of very laborious calculations, which, while in themselves so small, were so admirably effective in introducing harmony and precision throughout the entire triangulation.

If, now, we turn once more to what Lambton calls "the sublime science of geodesy," which was held in such high regard by both him and Everest, we shall find that the great meridional arc between Cape Comorin and the Himalayas, on which they labored with so much energy and devotion, is not the only contribution to that science to which the Indian triangulation is subservient, but every chain of triangles—meridional, longitudinal, or oblique—may be made to throw light either on geodesy, the science of the figure of the earth, or on geognosy, the science of the earth's interior structure, when combined with corresponding astronomical arcs of amplitude. Thus, each of the several meridional chains of triangles may be utilized in this way, as their prototype has been, by having latitude observations taken at certain of their stations to give meridional arcs; and the several longitudinal chains of triangles may also be utilized—in combination with the main lines of telegraph—by electro telegraphic determinations of differential longitudes to give arcs of parallel. When the stations of the triangulation which are resorted to for the astronomical observations are situated in localities where the normal to the surface coincides fairly with the corresponding normal to the earth's figure, the result is valuable as a contribution to geodesy; when the normal to the surface is sensibly deflected by local attraction, the result gives a measure of the deflection which is valuable as a contribution to geognosy.

Having regard to these circumstances, I moved the Government to supply the Trigonometrical Survey with the necessary instruments for the measurement of the supplemental astronomical arcs; and as officers became available on the gradual completion of the successive chains of triangles, I employed some of them in the required determinations of latitude and differential longitude. It so happened that about the same time geodesists in Europe began to recognize the advantages to science to be acquired by connecting the triangulations of the different nationalities together, and supplementing them with arcs of amplitude. The "International Geodetic Association for the Measurement of degrees in Europe," was formed in consequence, and it has been, and is still, actively employed in carrying out this object; in India, however, the triangulation was complete and connected throughout, so that only the astronomical amplitudes were wanting. They are still in progress, but already meridional chains, aggregating 1,840 miles in length, and lying to the west of the Great Arc, have been converted into meridional arcs; and the three longitudinal chains from Madras to Mangalore, from Bombay to Vizagapatam, and from Kurrachee *via* Calcutta to Chittagong, of which the aggregate length is 2,600 miles, have been converted into arcs of parallel. In the former the operations follow the meridional course of the chains of triangles; in the latter they follow the principal lines of the electric telegraph, which sometimes diverge greatly from the direction of the longitudinal chains of triangles, the two only intersecting at occasional points; the astronomical stations are therefore placed at trigonometrical points which may happen to be nearest the telegraph lines

whether on the meridional or on the longitudinal chains, and their positions are invariably so selected as to form self-verificatory circuits which are usually of a triangular form, presenting three differential arcs of longitude; each of these arcs is measured independently as regards the astronomical work—though, for the third arc, there is usually no independent telegraph line, but only a coupling of the lines for the first and second arcs—and this has been proved to give such an excellent check on the accuracy of the operations that it is not too much to say that no telegraphic longitude operations are entirely reliable which have not been verified in some such manner.

Through the courtesy of Colonel Stotherd, Director-General of the Ordnance Survey, I am enabled to exhibit two charts, one of the triangulation of India, the other of that of Europe, which have recently been enlarged to the same scale in the Ordnance Survey Office at Southampton for purposes of comparison. The first is taken from the official chart of the Indian Survey, and shows the great meridional and longitudinal chains and Lambton's network of principal triangles, the positions of the base lines measured with the Colby apparatus, the latitude and the differential longitude stations, the triangular circuits of the longitudinal arcs, the stations of the pendulum, and the tidal operations which will be noticed presently, and the secondary triangulations to fix the peaks of the Himalayan and Sulimani ranges, and the positions of Bangkok in Siam, and Kandahar in Afghanistan, the extreme eastern and western points yet reached. The chart of the European triangulation has been enlarged from one published by the International Geodetic Association of Europe; in it special prominence is given to the Russian meridional arc, which extends from the Danube to the Arctic Ocean, and is 25° 20′ in length, and to the combined English and French meridional arc, 22° 10′ in length, which extends from the Balearic Island of Formentera in the Mediterranean, to Saxavord in the Shetland Islands. The aggregate length of the meridional arcs already completed in India is about equal to that of the English, French, and Russian arcs combined; but the longest in India is about $1\frac{1}{2}$° shorter than the Russian. As regards longitudinal arcs, I believe the two which were first measured in India, and were employed shortly afterwards by Colonel Clarke in his last investigation of the figure of the earth, are the only ones which have as yet been deemed sufficiently accurate to be made use of in such investigations, though arcs of much greater length have been measured in Europe. It would be interesting, if time permitted, to set forth the salient points of divergence between the systems of the Indian and the European surveys; I will only mention that in the southern part of the Russian arc, for a space of about 8° from the Duna to the Dneister, a vast plain, covered with immense and almost impenetrable forests, presented great obstacles to the prosecution of the work; the difficulty was overcome by the erection of a large number of lofty stations of observation, wooden scaffoldings which were 120, and even as much as 146, feet high, to overlook the forests. In Indian forests, as the Terai, on the borders between British and Nepalese territories, the stations were rarely raised to a greater height than 30 feet, or just sufficient to overtop the curvature, and all trees and other obstacles were cleared away on the lines between them; this was found the most expeditious and economical process. The stations were very substantial, with a central masonry pillar, for the support of a great theodolite, which was isolated from the surrounding platform for the support of the observer. The lofty Russian scaffoldings only sufficed for small theodolites, and they were so liable to shake and vibration that the theodolites had to be fitted with two telescopes to be pointed simultaneously by two observers at the pair of stations, the angle between which was being measured.

All the modern geodetic data of the Indian survey that were available up to the year 1880 were utilized by Colonel A. R. Clarke, C. B. of the Ordnance Survey, in the last of the very valuable investigations of the figure of the earth which he has undertaken from time to time. It will be obvious that new data tend to modify in some degree the conclusions derived from previous data, for the figure of so large a globe as our earth is not to be exactly determined

from measurements carried over a few narrow belts of its superficies. Thus, thirty years ago it was inferred that the equator was sensibly elliptic—and not circular, as had been generally assumed—with its major axis in longitude 15° 34′ east of Greenwich, but later investigations indicate a far smaller ellipticity, and place the major axis in west longitude 8° 15′. More significant evidence of the influence of new facts of observation in modifying previous conclusions is furnished by the French national standard of length, the meter, which was fixed at the ten-millionth part of the length of the earth's meridional quadrant, as deduced from the best geodetic data available up to the end of the last century; but it is now found to be nearly $\frac{1}{5000}$th part less than the magnitude which it is supposed to represent, the difference being about a hundred times greater than what would now be considered an allowable error in an important national standard of measure.

The Indian survey has also made valuable contributions to geodesy and geognosy in an elaborate series of pendulum observations for determining variations of gravity, which throws light both on the grand variation from the poles to the equator that governs the ellipticity, and on the local and irregular variations depending on the constitution of the interior of the earth's crust. They were commenced in 1865 by Captain J. P. Basevi, on the recommendation of Gen. Sabine and the Council of the Royal Society, with two pendulums, one of which the General had swung in his notable operations which extend from a little below the equator to within 10° of the pole. Captain Basevi had nearly completed the operations in India, and had taken swings at a number of the stations of the Great Arc, and at various other points near mountain ranges and coast lines, when he died of exposure in 1871 at a station on the high table-lands of the Himalayas, while investigating the force of gravity under mountain ranges. Major Heaviside swung the pendulums at the remaining Indian stations, then at Aden and Ismailia on the way back to England, and finally at the base station, the Kew Observatory. Afterwards they and a third pendulum were swung at Kew and Greenwich by Lieutenant-Colonel Herschel, who took all three to America, swung them at Washington, and then handed them over to officers of the United States Coast Survey, by whom they have been swung at San Francisco, Auckland, Sydney, Singapore, and in Japan.

The pendulum operations in India have been successful in removing from the geodetic operations the reproach which had latterly been cast on them, that their value has become much diminished since the discovery that the attraction of the Himalayan mountains is so much greater than had previously been suspected, that it may have materially deflected the plumb-line at a large number of the astronomical stations of the Great Arc, and injuriously influenced the observations. Everest considered the effects of the Himalayan attraction to be immaterial at any distance exceeding sixty miles from the feet of the mountains; but in his days the full extent and elevation of the mountain masses was unknown, and their magnitude was greatly underestimated. Afterwards, when the magnitude became better known, Archdeacon Pratt, of Calcutta, a mathematician of great eminence, calculated that they would materially attract the plumb-line at points many hundred miles distant; he also found that everywhere between the Himalayas and the ocean, the excess of density of the land of the continent, as compared with the water of the ocean, would combine with the Himalayan attraction and increase the deflection of the plumb-line northwards, towards the great mountain ranges, and that under the joint influence of the Himalayas and the ocean the level of the sea at Kurrachee would be raised 560 feet above the level at Cape Comorin.

But, as a matter of fact, the Indian arc gave a value of the earth's ellipticity which agreed sufficiently closely with the value derived from the arcs measured in all other quarters of the globe, to show that it could not have been largely distorted by deflections of the plumb-line; thus, it appeared that whereas Everest might have slightly underestimated the Himalayan attraction, Pratt must have greatly overestimated it. His calculations were, however, based on reliable data, and were indubitably correct. For

some time the contradiction remained unexplained, but eventually Sir George Airy put forward the hypothesis that the influence of the Himalayan masses must be counteracted by some compensatory disposition of the matter of the earth's crust immediately below them, and in which they are rooted; he suggested that the bases of the mountains had sunk to some depth into a fluid lava which he conceived to exist below the earth's crust, and that the sinking had caused a displacement of dense matter by lighter matter below, which would tend to compensate for the excess of matter above. Now, Pratt's calculations had reference only to the visible mountain and oceanic masses, and their attractive influence—the former positive, the latter negative—in a horizontal direction; he had no data for investigating the density of the crust of the earth below either the mountains, on the one hand, or the bed of the ocean, on the other. The pendulum observations furnished the first direct measures of the vertical force of gravity in different localities which were obtained and these measures revealed two broad facts regarding the disposition of the invisible matter below: first, that the force of gravity diminishes as the mountains are approached, and is very much less on the summit of the highly-elevated Himalayan table-lands than can be accounted for otherwise than by a deficiency of matter below; secondly, that it increases as the ocean is approached, and is greater on islands than can be accounted for otherwise than by an excess of matter below. Assuming gravity to be normal on the coast lines, the mean observed increase at the island stations was such as to cause a seconds pendulum to gain three seconds daily, and the mean observed decrease in the interior of the Continent would have caused the pendulum to lose $2\frac{1}{2}$ seconds daily at stations averaging 1,200 feet above the sea level, 5 seconds at 3,800 feet, and about 22 seconds at 15,400 feet—the highest elevation reached—in excess of the normal loss of rate due to height above the sea.

Pratt was strongly opposed to the hypothesis of a substratum, or magma, of fluid igneus rock beneath the mountains; he assumed the earth to be solid throughout, and regarded the mountains as an expansion of the invisible matter below, which thus becomes attenuated and lighter than it is under regions of less elevation, and more particularly in the depressions and contractions below the bed of the ocean. And certainly we seem to have more reason to conclude that the mountains emanate from the subjacent matter of the earth's crust than that they are as wholly independent of it as if they were formed of stuff shot from passing meteors and asteroids; any severance of continuity and association between the visible above and the invisible below, appears, on the face of it, to be decidedly improbable.

The hypothesis of sub-continental attenuation and sub-oceanic condensation of matter, is supported by the two arcs of longitude on the parallels of Madras and Bombay; for, at the extreme points of these arcs, which are situated on the opposite coast lines, the horizontal attraction has been found to be not landwards, as might have been anticipated, but seawards, showing that the deficient density of the sea, as compared with the land, is more than compensated by the greater density of the matter under the ocean than of that under the land.

While on the subject of the constitution of the earth's crust, I may draw attention to the circumstance that the tidal observations which have been carried on at a number of points on the coasts of India, as a part of the operations of the Survey, tend to show that the earth is solid to its core, and that the geological hypothesis of a fluid interior in untenable. They have been analyzed by Prof. G. H. Darwin, with a view to the determination of a numerical estimate of the rigidity of the earth, and he has ascertained that while there is some evidence of a tidal yielding of the earth's mass, that yielding is certainly small, and the effective rigidity is very considerable, not so great as that of steel, as was at first surmised, but sufficient to afford an important confirmation of the justice of Sir William Thomson's conclusion as to the great rigidity.

The Indian pendulum observations have been employed by Colonel Clarke, in combination with those taken in other parts of the globe, to determine the earth's ellipticity. Formerly there was wont to be a material difference between

the ellipticities which were respectively derived from pendulum observations and direct geodetic measurements, the former being somewhat greater than $\frac{1}{290}$, the latter somewhat less than $\frac{1}{300}$; but as new and more exact data became available, the values derived from these two essentially independent sources became more and more accordant, and they now nearly agree in the value $\frac{1}{293}$.

As a part of the pendulum operations, a determination of the length of the seconds pendulum was made at Kew by Major Heaviside, with the pendulum which had been employed for the same purpose by Kater early in the present century, when leading men of science in England believed that in the event of the national standard yard being destroyed or lost, the length might be reproduced at any time with the aid of a reversible pendulum. In consequence of this belief, an Act of Parliament was passed in 1824 which defined the relations between the imperial and the seconds pendulum, the length of the former being to that of the latter—swung in the latitude of London, in a vacuum, and at the level of the sea—in the proportion of 36 inches to 39.1393 inches. Thus, while the French took for their unit of length the ten millionth part of the earth's meridional quadrant, the English took the pendulum swinging seconds in the latitude of London. In case of loss, the yard is obviously recoverable more readily and inexpensively by reference to the pendulum than the meter by reference to the quadrant; it is also recoverable with greater accuracy; still the accuracy is not nearly what would now be deemed indispensable for the determination of a national standard of length, and it is now generally admitted that every pendulum has certain latent defects, the influence of which cannot be exactly ascertained. Thus, the instrument cannot be relied on as a suitable one for determinations of absolute length; but, on the other hand, so long as its condition remains unaltered, it is the most reliable instrument yet discovered for differential determinations of the variations of gravity. In truth, however, the pendulum is a very wearisome instrument to employ even for this purpose, for it has to be swung many days, and with constant care and attention to give a single satisfactory determination; thus, if such a thing can be invented and perfected as a good differential gravity meter, light and portable, with which satisfactory results can be obtained in a few hours, instead of many days, the boon to science will be very great.

The trigonometrical operations fix with extreme accuracy two of the co-ordinates—the latitude and longitude—which define the positions of the principal stations; but the third co-ordinate, the height, is not susceptible of being determined by such operations with anything like the same degree of accuracy, because of the variations of refraction to which rays of light passing through the lower strata of the atmosphere are liable, as the temperature of the surface of the ground changes in the course of the day. In the plains the apparent height of a station ten to twelve miles from the observer has been found to be upwards of 100 feet greater in the cool of the night than in the heat of the day, the refraction being always positive when the lower atmospheric strata are chilled and laden with dew, and negative when they are rarified by the heat radiated from the surface of the ground. At hill stations the rays of light usually pass high above the surface of the ground, and the diurnal variations of refraction are comparatively immaterial, and very good results are obtained by the expedient of taking the vertical observations between reciprocating stations at the same hour of the day, and as nearly as possible at the time of minimum refraction; but in the plains this expedient does not usually suffice to give reliable results. The hill ranges of central and those of northern India are separated by a broad belt of plains, which embraces the greater portion of Sind, the Punjab, Rajputana, and the valley of the Ganges, and is crossed by a very large number of the principal chains of triangles, on the lines where the chart shows stretches of comparatively small triangles, which are, in most instances, of considerable length. Thus it became necessary to run lines of spirit levels over these plains, from sea to sea, to check the trigonometrical heights. The opportunity was taken advantage of to connect all the levels which had been executed for irrigation and other public

works, and reduce them to a common datum; and eventually lines of level were carried along the coast and from sea to sea to connect the tidal stations. The aggregate length of the standard lines of level executed up to the present time is nearly 10,000 miles, and an extensive series of charts of the levels derived from other departments of the public service and reduced to the survey datum has already been published.

The survey datum which has been adopted for all heights, whether deduced trigonometrically or by spirit leveling, is the mean sea level as determined, either for initiation or verification, by tidal observations at several points on the coast lines. At first the observations were restricted to what was necessary for the requirements of the survey, and their duration was limited to a lunar month at each station. In 1872 more exact determinations were called for, to ascertain whether gradual changes in the relative level of land and sea were taking place at the head of the Gulf of Cutch, as had been surmised by the geological surveyors, and observations were taken for over a year at three tidal stations on the coasts of the gulf, to be repeated hereafter when a sufficient period had elapsed to permit of a measurable change of level having taken place. Finally, in 1875, the Government intimated that, as "the great scientific advantages of a systematic record of tidal observations on Indian coasts had been frequently urged and admitted," such observations should be taken at all the principal ports and at such points on the coast lines as were best suited for investigations of the laws of the tides. In accordance with these instructions, five years' observations have been made at several points, and new stations are taken up as the operations at the first ones are completed.

The initiation of the latter and more elaborate operations is due, in great measure, to the recommendations of the Tidal Committee of the British Association, of which Sir William Thomson was President. The tidal observations have been treated by the method of harmonic analysis advocated by the committee. The constants for amplitude and epoch are determined for every tidal component, both of long and of short periods, and, with their aid, tide-tables are now prepared and published annually for each of the principal ports; and, further, it is with them that Professor G. H. Darwin made the investigation of the effective rigidity of the earth, which I have already mentioned. The very remarkable waves which were caused by the earthquake on December 31, 1881, in the Bay of Bengal, and by the notable volcanic eruptions in the Island of Krakatoa and the Straits of Sunda, on August 27 and 28, 1883, were registered at several of the tidal stations, and thus valuable evidence has been furnished of the velocities of both the earth-wave and the ocean-wave which are generated by such disturbances of the ordinarily quiescent condition of the earth's crust.

I must not close this account of the non-graphical, or more purely scientific, operations of the great Trigonometrical Survey of India without saying something of the officers who were employed thereon, under the successive superintendence of Everest, Waugh, and myself. A considerable majority were military, from all branches of the army—the cavalry and infantry, as well as the corps of engineers and artillery; the remainder were civilians, mostly promoted from the subordinate grades. Prominent shares in the operations were taken by Lieutenant Renny, Bengal Engineers, afterwards well known in this neighborhood as Colonel Renny Tailyour, of Borrowfield, in Forfarshire, of whom and his contemporary, Lieutenant Waugh, Everest retiring, reported in terms of the highest commendation; by Reginald Walker, of the Bengal Engineers, George Logan, George Shelverton, and Henry Beverley, all of whom fell victims to jungle fever; by Strange, F. R. S., of the Madras Cavalry, whose name is associated with the construction of the modern geodetic instruments of the Survey; by Jacob—afterwards Government Astronomer at Madras—Rivers and Haig, all of the Bombay Engineers; Tennant, C. I. E., F. R. S., Bengal Engineers, afterwards Master of the Mint in Calcutta; Montgomerie, F. R. S., of the Bengal Engineers, whose name is best remembered in connection with the Trans Himalayan geographical operations; James Basevi, of the Bengal Engineers, who so sadly died of exposure while engaged on the pendulum operations in the higher

Himalayas; Branfill, of the Bengal Cavalry; Thuillier, Carter, Campbell, Trotter, Heaviside, Rogers, Hill, and Baird, F. R. S., all engineer officers; also Hennessey, C. I. E., F. R. S., M. A., Herschel, F. R. S., and Cole, M. A., whose names are intimately associated with the collateral mathematical investigations, and the final reduction of the principal triangulation.

The Trigonometrical Survey owes very much to the liberal and even generous support which it has invariably received from the Supreme Government, with the sanction and approval, first of the Directors of the East India Company, and afterwards of the Secretary of State for India. In times of war and financial embarrassment the scope of the operations has been curtailed, the establishments have been reduced, and some of the military officers sent to join the armies in the field; but, whatever the crisis, the operations have never been wholly suspended. Even during the troubles of 1857–58, following the mutiny of the native army, they were carried on in some parts of the country, though arrested in others; and the then Viceroy, Lord Canning, on receiving the reports of the progress of the operations during that eventful period, immediately acknowledged them to the Surveyor-General, Colonel Waugh, in a letter from which the following extract is taken:

"I cannot resist telling you at once with how much satisfaction I have seen these papers. It is a pleasure to turn from the troubles and anxieties with which India is still beset, and to find that a gigantic work, of permanent peaceful usefulness, and one which will assuredly take the highest rank as a work of scientific labor.and skill, has been steadily and rapidly progressing through all the turmoil of the last two years."

The operations have been uninfluenced by changes of *personnel* in the administration of the Indian Empire, as Governor-Generals and Viceroys succeeded each other, but have met with uniform and consistent support and encouragement. It may well be doubted whether any similar undertaking, in any other part of the world, has been equally favored and as munificently maintained.

In conclusion, I must state that I have purposely said nothing of the graphical operations executed in the Trigonometrical and other branches of the Survey of India, because they are more generally known, their results appear in maps which speak for themselves, and time would not permit of my ttempting to describe them also. They comprise, *first*, the general topography of all India, mostly on the standard scale of 1 inch to the mile; *secondly*, geographical surveys and explorations of regions beyond the British frontier, notably such as are being carried on at the present time on the Russo-Afghan frontier by Major Holdich and other officers of the Survey; *thirdly*, the so-called Revenue Survey of the British districts in the Bengal Presidency, which is simply a topographical survey on an enlarged scale—4 inches to the mile—showing the boundaries and areas of villages for fiscal requirements; and, *fourthly*, the Cadastral Survey of certain of the British districts in the Bengal Presidency, showing fields and the boundaries of all properties, on scales of 16 to 32 inches to the mile. There are also certain large-scale surveys of portions of British districts in the Madras and Bombay Presidencies, which, though undertaken originally for purely fiscal purposes,. by revenue and settlement officers working independently of the professional survey, have latterly been required to contribute their quota to the general topography of the country. And of late years a survey branch has been added to the Forest Department, to provide it with working maps constructed for its own requirements on a larger scale than the standard topographical scale, but on a trigonometrical basis, and in co-operation with the Survey Department. But this brief capitulation gives no sort of idea of the vast amount of valuable topographical and other work for the requirements of the local administrations and the public at large—always toilsome, often perilous—which has been accomplished, quite apart from and in quantity far exceeding the non-graphical and more purely scientific work which I have been describing. Its magnitude and variety are such that a mere list of the officers who have taken prominent shares in it, from first to last, would be too long to read to you. Three names, however, I must mention: *First*, that of General Sir

Henry Thuillier, who became Surveyor-General on the same day that I succeeded to the superintendence of the Great Trigonometrical Survey, and with whom I had the honor of co-operating for many years; under his administration a much larger amount of topography was executed than under any of his predecessors, and a great impetus was given to the lithographic, photographic, engraving, and other offices in which the maps of the survey are published; *secondly*, that of Colonel Sconce, who became Deputy Surveyor-General soon after my accession in 1878 to the Surveyor-Generalship, and with whom I was associated for some years, much to my gratification and advantage in various matters, but more particularly in the establishment of cadastral surveys on a professional basis at a moderate cost, to render them more generally feasible, which was a matter of the utmost importance for the administration of the more highly populated portions of the British provinces; and, *thirdly*, that of Lieut.-Colonel Waterhouse, who has for many years superintended the offices in which photography is employed, in combination with zincography and lithography for the speedy reproduction *en masse* of the maps of the Survey, and has done much to develop the art of photogravure, whereby drawings in brushwork and mezzotint may be reproduced with a degree of excellence rivaling the best copperplate engraving, and almost as speedily and cheaply as drawings ink pen and in work are reproduced by photo zincography.

Mr. Clements Markham's "Memoir on the Indian Surveys" gives the best account yet published of the several graphical surveys up to the year 1878. In that year the Trigonometrical, Topographical, and the Revenue branches, which up to that time had constituted three separate and almost independent departments, were amalgamated together into what is now officially designatad "the Survey of India." In the same year the chronicle so well commenced by Mr. Markham came to an end on his retirement from the India office—unfortunately, for it is a work of excellence in object and in execution, and most encouraging to Indian surveyors, who find their labors recorded in it with intelligent appreciation and kindly recognition.

LIQUID FUEL.

From "Iron."

The time-honored question of the utilization of hydro-carbons for steam-raising purposes has been once more brought prominently forward in this country by the practical application of a new system for effecting that object. This system is the invention of Mr. Percy F. Tarbutt, and it has been applied to the furnaces of an 800-ton steamship which has recently made a very satisfactory run from London to Leith and back. The success of this run, taken in conjunction with certain collateral circumstances to which we shall presently more fully refer, points to the possibility of the use of liquid fuel in the present connection becoming an accomplished fact at no distant period in this country. In other countries where the oil is a natural and plentiful product, its practical application for steam-raising purposes has long been common. In Great Britain, however, any success in adapting it to this use has generally been followed by an inordinate, and, therefore, prohibitory rise in the price of the fuel, which has extinguished the furnace and the hopes of the inventor at one and the same time. We have said that the question is a time-honored one, and, before proceeding to describe Mr. Tarbutt's method of solving it, it may be as well if we glance back at what has been attempted or accomplished in the past in utilizing liquid fuel. So long ago as 1830, Mr. H. Pinkus claimed to have used hydro-carbons in conjunction with streams of vapor for steam-raising purposes, and from that time down to the present, en-

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gineers and inventors have not, for any lengthened period, ceased to labor in the same direction. Richardson's petroleum furnace, as well as that of Bridges Adams, have both come under our personal observation in the past, and they were for many years under the constant notice of the officials in Woolwich Dockyard. In 1868 the Government permitted Wise, Field, and Aydon's system of using petroleum by the aid of an induced current to be applied to a marine boiler on board a steam yacht. The same system had also been previously applied to a Cornish boiler, at some large works in London, which we saw giving good results. The Admiralty also tried at Sheerness a somewhat similar plan, invented by Mr. S. E. Crow, but, as in the Woolwich trials, without anything practical resulting. In the same year, which appears to have been marked by a sudden outbreak of inventive activity in connection with the subject of liquid fuel, Dorsett's petroleum furnace was fitted under the boiler of the steamship *Retriever*, of 90 horse-power and 500 tons burden, and some very successful runs were made with her, at which we were present. The excellent results obtained in the *Retriever* led Mr. Dorsett to apply the system to re-heating furnaces, and a furnace of this class was fitted up at the works of Messrs. Camroux & Co., of Deptford, and we believe, successfully run for a considerable length of time.

In the same year corresponding attention was paid to the subject of liquid fuel in France, one system tried there being that of M. Verstraet, a chemist, in the development of whose invention M. Sainte-Claire-Deville took an active part. The Emperor of the French also took a personal interest in the question of liquid fuel. M. Verstraet's system, which consisted in conducting, or rather inducting, the gases of the oil to the furnace by a current of air was applied to a locomotive on the Eastern of France Railway, and upon the occasion of the Emperor visiting the camp at Chalons, the train was drawn by the engine thus fitted. His Majesty rode on the footplate of the engine in company with MM. Sauvage, Dieudonne, and Sainte-Claire-Deville. In the same year, His Majesty also made a run in the *Puebla*, a steamer in which mineral oil was employed to raise the steam for the engines. In America, liquid fuel has been used both on locomotives and in steamers, at one time, we believe, to a considerable extent. But, notwithstanding the advantages offered in the way of cheap and plenteous liquid fuel, it would seem to have but a very limited application in practice for steam-raising purposes. In Russia, a very different condition of matters exists, inasmuch as for several years past petroleum refuse has been used as fuel in the locomotives on the Grazi and Tsaritsin Railway in South-east Russia, the first trials on that line having been made in 1874. Besides this, numbers of steamers are now running on the Caspian Sea which are using liquid fuel. As far as the practical adoption of the principle in Great Britain and France has gone nothing further appears to have resulted. The reason for this we believe to be that which we have already indicated, namely, that directly a demand was created for the class of liquid fuel used, and which at that time was a drug on the market, the prices went up to a prohibitive extent. But we appear to be within a measurable distance of a change for the better in this respect, inasmuch as —and this is the collateral circumstance to which we have already alluded—in consequence of the comparative scarcity and dearness of petroleum in this country, a fleet of large tank steamers is now being built by the Russian Black Sea Navigation Company to bring regular supplies of the Russian oil to Europe in bulk. Given constant and adequate supplies, and an efficient means of utilizing them in boiler and other furnaces, and the question of liquid fuel would appear to be solved, other things, of course, being equal.

To bring the question of liquid fuel down to the present time, we must now refer to the system of Mr. Tarbutt (of the firm of Tarbutt & Quentin, of 75 Lombard Street, London), which we recently inspected as fitted on board the steamship *Himalaya*. This vessel is a trader of 100 horse-power, nominal, and 800 tons burden. She is 210 feet long, with 28 feet beam, and is fitted with compound engines, driving a screw propeller. The boilers have three furnaces, each of which has an openwork firebrick lining on the principle of the Siemens regenerative system. At the end

of each furnace is a fire-brick baffle, having an aperture through which the heat passes to the tubes from the furnace, or, as it may more correctly be called, the combustion chamber. In this chamber is a coil of iron pipe, one end of which is connected with the steam space of the boiler, and the other opens out at the door of the chamber. This coil is for the purpose of superheating steam taken from the boiler, and by which an induced current is set up, which carries the petroleum forward into the combustion chamber. In order to enable it to do this the petroleum nozzle is placed within the steam pipe at the opening where it delivers its jet, so that an annular space is formed, through which the steam rushes, and, combining with the small but regular flow of the oil, produces a large volume of flame within the chamber. The oil is stored in tanks on the main deck, whence it flows by gravity to the delivery nozzles at the furnaces. The whole apparatus is very simple, and easily adjustable. One important feature is that, in the event of oil not being obtainable at any port where fuel is required, the oil-burning fitting can be removed, and the fire-bars for burning coal be replaced in a very short time. Another important feature of the system, which we must not omit to mention, is the method of starting the furnace, which is effected by a very simple arrangement, whereby sufficient steam is quickly raised to start and maintain combustion until the steam pressure in the boiler is sufficient for that purpose. The *Himalaya* belongs to the Marahu Petroleum and Oil-produce Company, of Suffolk House, Cannon Street, London, and by them has been fitted with the apparatus we have described in order to practically and commercially test the system. She will, however, eventually be renamed the *Marahu*, after her owners, the Marahu Company. The coal-carrying capacity of this vessel is about 240 tons, and her consumption of this fuel is stated to be ten tons per day. She will now require to carry only 110 tons of oil, her consumption of liquid fuel being put at 4½ tons per day, thus giving a great increase of cargo capacity. It is intended to employ her for trading purposes along the coast of Brazil, where her supply of liquid fuel will be regularly obtained from the works of the company to which she belongs. We recently inspected the furnaces and oil equipment of the *Himalaya* while in dock, and witnessed a demonstration of the satisfactory working of the apparatus, combustion being nearly perfect, as evidenced by the very small amount of smoke that issued from the funnel. A fairly steady steam pressure of 55 lbs. per square inch was maintained, the steam, of course, being blown off as made. On her return journey from Leith, the *Himalaya* arrived several hours sooner than was expected, having made the quickest voyage ever performed by her, and this in spite of the circumstance that one of her propeller blades was broken off in a collision with a barge in port. It is stated that the vessel is very much under-boilered, but that with the liquid fuel she made more steam than she ever had made with coal.

Taking the circumstances of the case generally, including the attempt now being made by Russian enterprise to secure a regular and full supply of oil to this country, it would appear as though the solution to the liquid-fuel problem was at hand. That solution would mean an enormous saving in our solid fuel, coal, whilst our steamships would be relieved of some 50 per cent. of their fuel weight, which could either be assigned to cargo, or, where long voyages had to be made, to a double supply of liquid fuel.

REPORTS OF ENGINEERING SOCIETIES.

ENGINEERS' CLUB OF PHILADELPHIA—RECORD OF REGULAR MEETING, NOVEMBER 21, 1885.—Past President Rudolph Hering in the chair.

The Secretary presented, for Mr. W. S. Church, a large number of photographs, tracing, pamphlets, and other documents, illustrating the design and progress of the New Croton Aqueduct, and read two communications from Mr. Church. He says: "The 'ground' through which the tunnel is advancing, is largely gneiss with considerable limestone, felspar, and occasional quartz seams. The dips are so vertical that much roof rock comes away. This trouble is increased by the too free use of high explosives near the perimeter of the vertical section, so that the area excavated runs from 25 to 50 per cent. in excess.

"A most careful system of measuring and recording just what is excavated is being carried out. A vertical dial, which the boys call 'The Sun Flower,' is set up every 10 ft., and oftener if necessary, and radial measurements

taken to all the inequalities of the section; these measures are plotted on the diagrams, and the areas estimated with the planimeter

"The principal difficulty that the line has yet encountered, is the Gould Swamp It has finally been decided to under-run this in solid rock with a siphon, making a blow-off below grade, and draining by an adit out into the Hudson River.

"In Vol. V., No. 1, page 13, in a discussion of Mr. A. Harvey Tyson's paper on 'Pollution in Storage Reservoirs,' I notice that Mr. Charles G. Darrach says, 'I would call attention to the fact that in the proposed Quaker Bridge Dam for the New Croton Aqueduct no provision seems to have been made, as far as can be learned from published plans, for draining off the water from the lower levels. As this dam will be of almost unprecedented depth, the same trouble may be expected as in Baltimore and Reading, unless this precaution is taken.' The Club will observe, from the drawing sent, that this criticism is fully met, and that the big reservoir of the Croton will, when constructed according to present designs, have the best *circulation* of any reservoir in the world."

Mr. Jno. S. Elliott presented a paper on "Specifications as Affecting the Dimensions of Iron Railroad Bridges." As closely as harmonize theory and practice in bridge engineering, and notwithstanding the agreement amongst builders there still remain differences and inconsistencies in matters. Example given of two spans, built by Detroit Bridge Iron Co., one 154 ft., the other 162 ft., in length, the first has 30 per cent. more metal in it, showing to what extent different rolling load, requirements and dimension formulæ may affect metal amounts. The author reviewed some departures from the usual methods of distributing the load for purposes of calculating the strains, showing them to be unnecessary refinements. The subject of wind bracing was taken up, and one important principle involved in the dimensioning of the chord members for wind stresses shown to be applicable to double track through trusses—making a saving of between 15 and 20 per cent. in material. It is this: No addition to chord members for wind stresses is made, unless the combined wind and load stresses cause a strain in the member over and above a certain proportion of the maximum dead and live load stresses. In other words, as it is but seldom the case that all possible stresses combine, no addition to chord members will be made unless a certain strain limit is passed. The same principle should hold good for a double track through span, where any one of the two trusses but seldom is required to resist all possible attacking forces. Wohler's law with Launhardt's and Weyrauch's deductions then treated and examples given of variations in dimensions of existing bridges caused by using them. Economy to use these formulæ in long spans and to the best of the author's belief, the firm of Wilson Bros., members of the Club to be the first to use them in this country scientifically.

A discussion followed upon the paper of Mr. James Christie, upon the "Adaptation of Steel to Structural Work." Mr. Thos. M. Cleemann thought the use of steel instead of iron by engineers was dependant principally on the manufacturers producing a perfectly uniform and reliable product, which at present they do not seem to do. He thought that the advantage of using a cast metal was in favor of steel, by which struts could be made of a hollow circular section, requiring least material, and the punching of holes for fastening pieces together by riveting, which especially weakens steel of a high grade, could be dispensed with.

Mr. James Christie said in reply, that it was very improbable that struts would ever again be made directly from castings. Aside from the difficulty of maintaining a uniform thickness of metal, the cost of construction would be greater than by the present method of building up rolled material.

Professor Wm. H. Burr said the steel question presents itself to engineers under two entirely different aspects. The first involves the character of the metal *per se;* and the second is based upon the consideration of the influence of this metal on structural design. In the first place, although improvements in the uniformity of production can yet be made, steel makers, by either the Bessemer or open-hearth processes, are ready to work under any physical specifications affecting uniformity that may be demanded by the best engineering practice of the present time; and it may be safely asserted that increased uniformity will keep pace with any demand.

Unfortunately, however, there seems to be considerable diversity in the results of experiences with the many and varied shop manipulations necessary to the completion of the structural member. Mr. Christie tells us that in supplementing his most admirable tests on angle-iron struts, by those on composite riveted columns, he found the ultimate unit of stress in the latter essentially equivalent to that realized in the former. On the other hand, I am credibly informed by the chief inspector of an extensive railway system, that some full-sized high Bessemer steel latticed columns built for a large bridge failed, when tested to destruction, to give much, if any, excess over corresponding wrought iron columns These and other similar results suggest the possibility, or even probability, that the known sensitiveness of high steel demands a more extensive experimental experience with finished bridge members before the general use of such metal in columns can be considered satisfactory. Low structural steel of 60,000 to 65,000 pounds ultimate tensile resistance, is capable of any duty in the finished structure in the most satisfactory manner, and high steel of 80,000 to 90,000 pounds ultimate tensile resistance will eventually be equally reliable, but there are serious reasons for much care in its present use. The effect of the introduction of steel on structural design has not yet received the same consideration as that of constructive processes. With the increased working stresses allowed in steel, the coefficient of elasticity remains essentially the same as for wrought iron, with its lower allowable stresses. With the same design in both metals, the result is an increase of strains for steel in direct proportion to the unit stresses, and precisely the

same proportional increase of deflections. The present and increasing requirements for rapidly moving loads make this a very serious aspect of the question, and give rise to a corresponding modification of design, so that proper stiffness as well as strength may be maintained. A comparison of the deflections of the Niagara and St. John's cantilevers, shows very clearly the effect of a constant coefficient of elasticity with an increased working stress. The principal dimensions of these structures are sufficiently near in value to afford a very interesting comparison. The greatest deflection of the Niagara Bridge, with its high steel compression members, with working stresses that cannot be far from 9,000 to 10,000 pounds, in combination with wrought iron tension members, was $7\frac{5}{16}$ inches; while that of the St. John's Bridge, with all members of about 60,000 pound steel and corresponding working stresses, was 4 inches. A proper allowance for the compression of the steel piers of the former leaves a remaining difference of over 2 inches. Again, the effect of alternate stresses of opposite kinds on the design of steel members, is still a matter in almost a purely conventional state. The experiments of Weyrauch and Spargenberg are of the right kind, and constitute a long step in the right direction; but it must be borne in mind that these experimenters treated specimens and not structural members. The ultimate physical condition of steel furnishes strong reasons for believing that its fatigue under compression will be considerably less than that of wrought iron.

Mr. George S. Strong presented an illustrated description of Rack Rail Appliances for railroads with very heavy grades.

Mr. J. Foster Crowell presented an illustrated paper upon Masonry Arches, treating mathematically the determination of dimensions of voussoirs in difficult cases, and giving the result of his experience as to methods of withdrawing centers.

Mr. A. R. Roberts exhibited an appliance for fastening the Floor Timbers of Highway Bridges to the iron I-beams of the floor system. It consists of a piece of flat wrought iron cut from the ends toward the middle, the divided portions being bent at right angles to the piece, so that one opposite pair, after being ragged, can be driven in the wood, and the other pair bent under the flange of the iron beam.

Mr Kenry G. Morris introduced Mr. P. Oestburg, who exhibited specimens of and described the Miris Metal Castings, which are made from wrought iron, and have a very high ductility.

Mr. Wm. H Dechant presented a description of a Movable Dam and Caisson Operating Truck, illustrated by a small model and photo-lithograph plates. He claims a number of advantages in the system over the French or Chanoine system of movable dam, constructed by the United States Government at Davis' Island, below Pittsburgh, namely—a wicket of more simple construction, having a less number of wearing parts, and more positive action; less liability of being damaged by ice, snags, or any other body passing over them when down; a simple appliance to throw the wickets down either separately or collectively; a caisson operating truck, to enable one wicket, or a certain number of them, to be quickly and effectually enclosed from the water above the dam, to allow repairs to be made, and also to enable the attendants to get immediately over the wickets and dam, so as to make careful examinations, and be in a positive position to raise the wickets, making it practicable, wherever necessary, to use steam power to operate the dam, instead of depending upon manual labor. The system also applies to flush strips on top of permanent dams, and they are in practical use on several of the dams on the Schuylkill Navigation: where the flush strips from 10 to 18 inches in height are used, they are operated directly by a man walking out along the comb of the dam, one man being able to raise or lower such a wicket 10 feet long with ease.

AMERICAN SOCIETY OF CIVIL ENGINEERS—NOVEMBER 4th, 1885.—Vice-President G. S Greene, Jr., in the chair.

The following candidates were elected as members: Edward Sherman Gould, Yonkers, N. Y.; Benjamin Dwight Green, Oswego, N. Y.; Simpson Clark Heald, Worcester, Mass.; Thomas Franklin Richardson, El Paso, Texas; and as Fellow of the Society, Coddington Meyer, New York City.

The following amendment to the by-laws was regularly proposed:

To amend section 24, 5th clause, by substituting the word "December" for the word "November"

The Board of Direction was requested to issue a circular calling the attention of members to the desirability of adding to the number of junior members, and of exercising their personal influence with young men towards inducing them to make application in the ordinary way for junior membership.

A paper read by Mr F. Collingwood, M. Am. Soc. C. E., on "The Behavior of Cement Mortars under Various Contingencies of Use, with a Brief Discussion of Several Tests," was read. This paper calls attention to the desirability of securing observations upon the expansion and contraction of mortars when setting, and also of the compression at various ages under loads up to disintegration, at successive periods, both with pure cement, with various mixtures of sand, with concrete and with lime mortars, and also, in addition, to make observations of the same nature upon various building materials. Attention was also called to the importance of measuring actual compressions in walls and masses of masonry, and also as to the setting of mortars if placed wet, and the best method under such circumstances. Suggestion were made as to desirable methods of securing these observations. Changes in dimensions of masonry by changes of temperature were also referred to. This general subject, in its various relations, will be considered by a committee, which has been appointed in pursuance of the action at the last annual meeting.

NOVEMBER 18th, 1885—Vice-President G. S. Greene, Jr., in the chair.

Discussions were presented on "Wind Strains in Bridges," on "Formulæ for the Weight of Iron and Steel Railway Bridges," on "Canals and Railways," "Ship Canals and Ship Railways."

An ingenious instrument for the accurate drawing of curves for railways and other purposes was exhibited and explained by Mr. A. Marischal, C. E. In connection with the work of the Committee on Uniform Standard Time, a new clock-dial was exhibited. The arrangement of this dial is such that, by a simple attachment, the figures representing the hours are automatically changed at the proper times, so that they represent the morning and afternoon hours consecutively.

ST. LOUIS ENGINEERS' CLUB—November 18, 1885.—Executive Committee recommended that the meetings be held on the first and third Wednesdays of each month during the session. On motion the recommendation was adopted.

The Secretary then read a programme for the Winter:—Dec. 2—C. M. Woodward, "Theory of Ammonia Refrigerators;" Dec. 16—Thos. J. Whitman, History of the St. Louis Water Works;" Jan. 6—J. A. Seddon, "Cross Sections of Uniform Flow in River Physics;" Jan. 20—P. M. Bruner, "The Use of Hydraulic Cements;" Feb. 3—Chas. C. Brown; Feb. 17—Chas. W. Melcher, "The Theory of the Sustaining Power of an Air Jet;" March 3—Robert E. McMath, "The Future drainage of St. Louis;" March 17—A. P. Man, "The Determination of Openings for Bridges and Culverts;" April 7—W. Paul Gerhardt, "Disposal of Household Waste;" April 21—Geo. H. Pegram; May 5—S. Bent Russel, "Water Supply for Fire Service;" May 19—W. H. Allderdice; June 2—Report of Committee on Smoke Prevention.

Prof. J. B. Johnson read a paper on the Solar Azimuths by Transit Attachments and Base Line Measurements by the Steel Tape. General discussion followed.

To the Editor of Van Nostrand's Engineering Magazine:

SIR—The undersigned committee of the Engineers' Club, of St. Louis, would respectfully call your attention to the following action:

Whereas, The Engineers' Club, of St. Louis, did, on March 18, 1885, appoint a Committee to "Consider and report on the best means of improving the status of civil engineers in the service of the general government," and

Whereas, Said committee, after due deliberation, decided that this subject was not of sufficient general interest or importance to justify the Club in initiating or supporting a movement tending to simply legislate in the interest of a certain class, and

Whereas, The committee, in accordance with these views, reported to the Club, on May 13, 1885, that it "regrets to see the discussion of the subject turning aside from the broad question of creating an organization for the conduct of public works." And, furthermore, that "to this question, personal matters, past, present, or future, the value of the different schools and modes of training, or the honesty and truthfulness inculcated through certain associations, are alike foreign. There seems, therefore, to be need for conservative influence lest the utterances of individuals be taken as expressing the views and wishes of the engineering profession, and lest a discussion of a pure question of public policy degenerate into a controversy about matters of no consequence." And

Whereas, The committee was continued to consider this broader question and make an effort, through "correspondence and conference" with other societies, to reach some common ground of action ultimately terminating in a convention to formulate a plan for creating an organization to conduct our public works, and to consider all questions relating thereto. Therefore be it

Resolved, That this committee does not deem it expedient to send a representative to the convention called to meet in Cleveland for the purpose of promoting class legislation, a matter foreign to the declared purposes for which this committee was continued.

Resolved That copies of these resolutions be furnished the several engineering societies of the country.

ROBERT. E MCMATH,
J. A. OCKERSON,
J. B. JOHNSON,
H. S. PRITCHETT,
Committee.

ST. LOUIS, MO. Nov. 19, 1885.

ENGINEERING NOTES.

ANCIENT TUNNELS AND ARCHES.—Mr. Baker in his address to the British Association, said: "I have no doubt that as able and enterprising engineers existed prior to the age of steam and steel as exist now, and their work was as beneficial to mankind, though different in direction. In the important matter of water supply to towns, indeed, I doubt whether, having reference to facility of execution, even greater works were not done 2,000 years ago than now. Herodotus speaks of a tunnel 8 ft. square, and nearly a mile long, driven through a mountain in order to supply the city of Samos with water; and his statement, though long doubted, was verified in 1882 through the abbot of a neighboring cloister accidentally unearthing some stone slabs.

The German Archæological Society sent out Ernst Fabricius to make a complete survey of the work, and the record reads like that of a modern engineering undertaking. Thus, from a covered reservoir in the hills proceeded an arched conduit about 1,000 yards long, partly driven as a tunnel and partly executed on the "cut and cover" system adopted on the London underground railway. The tunnel proper, more than 1,100 yards in length, was hewn by hammer and chisel through the solid limestone rock. It was driven from the two ends like the great Alpine tunnels, without intermediate shafts, and the engineers of 2,400 years ago might well be congratulated for getting only some dozen feet out of level and little more out of line. From the lower end of the tunnel branches were constructed to supply the city mains and fountains, and the explorers

found ventilating shafts and side entrances, earthenware socket-pipes, with cement joints, and other interesting details connected with the water supply of towns.

In the matter of masonry bridges, as great works were undertaken some centuries ago as in recent times. Sir John Rennie stated, in his presidential address at the Institute of Civil Engineers, that the bridge across the Dee at Chester was the "largest stone arch on record." That is not so. The Dee Bridge consists of a single segmental arch 200 ft. span and 42 ft. rise; but across the Adda, in Northern Italy, was built, in the year 1377—more than 500 years ago—a similar segmental arch bridge of no less than 237 ft. span and 68 ft. rise. Ferario not long since published an account of this, for the period, colossal work, from which it would appear that its life was but thirty-nine years, the bridge having been destroyed for military reasons on December 21, 1416. I believe our American cousins claim to have built the biggest existing stone arch bridge in the world—that across the Cabin Johns Creek; but the span, after all, is only 215 ft., or 10 per cent. smaller than the 500-year-old bridge. In timber bridges, doubtless, the Americans will ever head the list, for the bridge of 340 ft. span built across the Schuylkill three-quarters of a century ago, will probably never be surpassed. Our ancestors were splendid workers in stone and timber, and if they had been in possession of an unlimited supply of iron and steel, I fear there would have been little left for modern bridge builders to originate.

IRON AND STEEL NOTES.

Silicon in Cast-iron.—Mr. Thomas Turner draws the following conclusions from some recent experiments:

1. That a suitable small addition of silicon to cast-iron almost entirely free from silicon is capable of producing a considerable improvement in the mechanical properties of the metal

2. That in these experiments the maximum values are probably reached with the following amount of silicon:

	Per cent.
Crushing strength.....	about 0.80
Modulus of elasticity.....	" 1.00
Relative density (in mass).....	" 1.00
Tensile strength.....	" 1.80
Softness and working qualities..	" 2.50

3. That when general strength is required, the amount of silicon should not vary much from about 1.4 per cent.; but that when special softness and fluidity are desirable, about 2.5 per cent. may be added. Even in the latter case, however, any increase upon 3 per cent. must be dangerous.

These conclusions are only strictly true under the circumstances of the author's experiments, but he hopes shortly to bring forward evidence from independent investigations to support his results. The cause of these results is discussed. The author is decidedly of the opinion that the production of graphitic carbon is not the only cause of these differences, but that, in addition to the indirect effect owing to the production of gray iron, the suitable addition of silicon has a direct and beneficial influence upon the mechanical properties of the metal.

New Process of Steel Manufacture.—During the last few months works specially laid out for a new process of steel manufacture have been established at Manchester by Messrs. Bott & Hackney. This is termed a direct process, and may be described as a compromise between the Bessemer and the crucible processes. An important advantage secured is that baked moulds are dispensed with, the castings being made in green sand, so that the many severe internal strains caused by hard moulds at the time of cooling are avoided. The firm are thus enabled to produce steel castings which are practically free from blowholes and shrinkage, notwithstanding that metal out of one ladle can be indiscriminately poured into elevator bucket moulds less than $\frac{1}{2}$ inch thick, or into moulds for heavy crank shafts. We have had an opportunity of inspecting a number of steel castings produced by this process which, under any ordinary method, would probably be considered impossible of production. Amongst these were mule sickles which had been twisted cold, then forged and hardened that they could be ground to a razor edge; and, as an example of intricate work, a pulsometer, with all its internal parts, has been successfully cast, which is probably the first time that a complicated apparatus of this description has been produced in a steel casting. There were also pulsometer valves, which, after turning, were hardened, and complicated lever castings perfectly soft and ductile, which, after being machined, were free from any defects, and were afterward hardened at the point where friction would require a wearing surface. The process enables malleable steel castings to be produced which are perfectly sound and reliable, and which can be ersily forged, and hardened as required, either in oil or water.

RAILWAY NOTES

An Electrical Tramway Engine.—Trials of a new electrical tramway engine are shortly to be made at Stratford, the engine being the invention of Mr. C. P. Elieson. This engine has for some time past been tested and run at the works of the North Metropolitan Tramway Company, London, England. The electrical and mechanical part has been constructed by the Electric Locomotive and Power Company. It appears that an extension will shortly be made of the tramway from Stratford down the Ilford Road, and that arrangements will be made later on to work this portion entirely by electric engines. Meanwhile an engine of greater power is being constructed with the view of showing what can be done on a railway. It is stated that the maximum of speed developed in the engine under notice is about eight miles an hour, but, if necessary, an engine can be constructed to run as fast as may be required for all practical purposes. The power is derived from 50 cells, containing about 280 amperes, and the current used varies from

about 60 amperes per hour at starting to about 35 amperes per hour when running.

AN ENGINE'S GREAT RECORD.—The Boston and Albany Railroad Company has been much interested in the performances of its locomotive passenger engine No. 137, which was built at the company's own shops. The following are the principal dimensions of the machine: Weight, 42 tons; cylinders, 18 by 22 in.; wheels, 68 in. diameter; boiler, 52 in. diameter; number of 2-in. tubes, 221; pressure, 160 lbs. This engine came out of shop April 23, 1883, and was taken in for general repairs October 30, 1885, having run daily 30 months and 7 days, or 921 days, making a total of 184,726 miles. During this time the engine lost 12 days for repairs, and deducting this from the total number of days run, the average number of miles run per day is 203. No repairs were made until April 27, 1884, when the engine had run 78,812 miles. During portions of the months of April and June and the whole of the month of May, 1885, the engine ran 400 miles per day, making (with extra trips Sundays) 10,910 miles in May, and a total of 26,740 miles in the above-named months, an average of 8,913 miles per month. The 12 days lost and the causes were as follows: April, 1884, 1 day, broken equalizer; July, 1884, 4 days, tires turned, one broken driving-box replaced and throttle ground; July, 1884, 4½ days, broken piston-rod; May, 1885, ½ day, broken piston-rod, front cylinder-head and casing; September, 1885, 2 days, broken driving-box. The driving-boxes were of cast iron. Steel is now being used, and no more trouble is expected from that source.

ORDNANCE AND NAVAL.

THE NEW NAVAL GUNS.—A long series of experiments have been made by the Ordnance Committee with the new breech-loading guns now in course of issue for the latest of the ironclads, the Impérieuse and the Warrior, and much useful information has been gained respecting the behavior and requirements of breech loading steel ordnance, the action of modern gunpowders, and collateral subjects. The particular gun designed for this service is known as the 9.2-in., of 22 cwt., and fires a projectile of 380 lbs. The first thing required was to determine the description of powder best adapted to the size and construction of the gun, and next the quantity calculated to give the maximum impetus to the shot within the stipulated strain upon the gun, for which it was decided, as a preliminary condition, that the pressure should not exceed 17½ tons. Cocoa powders were chiefly employed in the trials, previous experiments having conclusively demonstrated the superiority of these, the brown, powders over all descriptions of the black gunpowders of the past, but a few rounds of prismatic and "rifle large grain" were fired by way of comparison. The methods of restraining the action of the powders by increase of moisture and other devices, which have been carefully studied of late years, were closely observed and recorded, the result being the production of a brown powder at the government works, Waltham Abbey, which seems to have given complete satisfaction. A favorable peculiarity of the brown powders is found to be the small quantity of smoke, and even this dissipates immediately, but these powders also have a liquid residue, which is so hot that it will fire gunpowder after 20 or 30 seconds' exposure, and, therefore, a cause of danger when the gun is reloaded, the accident on board the Canada last November having probably had some such origin. Such misfortunes are hereafter to be guarded against by cooling the gun, and using a close-fitting sponge to clean out the chamber. Rottweil and Westphalian cocoa powders have also been fired from the gun, and have exhibited similar qualities, and, after some defects in the rotating range of the projectiles had been amended, the gun was found to make excellent practice, the errors up to about 4,000 yards being remarkably slight. The breech action opened and closed with great facility, and without the necessity of using the ratchet gear, and the fitting of metal disks on the obturator answered admirably in saving the obturator and confining the powder gases. The carriage also is reported favorably upon by the committee, the recoils being regular and well under control. The new velocimeter invented by Colonel Sebert for registering recoils, pressure on buffers, and velocity of projectiles through the gun, was used in these trials with good effect. Two of these instruments have been purchased by the War Department, and are now employed in most of the experiments at Woolwich. The results of these observations, and frequent inspections of the experimental gun, have, however, shown that there is something yet to learn on the subject of steel artillery, for, after firing 166 rounds, mostly with excessive charges, the gun had to be relined, and a tendency is displayed by all the guns of similar manufacture to enlarge the bore. The increase is almost infinitesimal, and no gun has yet been rendered unserviceable from this cause, but it has been thought advisable, pending some further modifications in the gun or projectiles, that the firing of these heavy breechloaders shall be restricted as far as practicable to reduced charges It is doubted whether under the present conditions it will be possible to prolong the life of a gun without relining for more than 200 battering charges. It will seldom be necessary for the Impérieuse or the Warrior to fire the full charge, and the imposition of the rule will therefore be attended with no practical inconvenience. With half charges, which are usual at practice, the guns will remain undeteriorated from probably 1,000 rounds.

MESSRS. FREDRICH KRUPP & Co. are at present, a correspondent says, manufacturing for the Italian Government four guns for a shore battery, which will be larger than any in the world. Each will weigh 120 tons, whilst a charge of 600 lbs. of gunpowder will be required for the firing of the projectile of one ton. The guaranteed range is five miles. The first of these monsters will be tested at Meppen on the firm's firing grounds, and transported to Italy on specially-built cars with sixteen axles, bridges and viaducts having to be strengthened in order to stand the weight.

An important addition has been made to the Swedish navy by the completion of the corvette Freja, built at the Kockum Engineering Works, Malmo. Her dimensions are—Length over all, 221 ft.: width, 41 ft.; and depth in the hold, 29 ft. She draws 19 ft. of water aft, and 16 ft. forward. The vessel is built throughout of soft, Swedish-Bessemer steel, and cased with a 3-in layer of teak and and a 2½-in. one of fir. Her engines are of 2,000 horse-power, and manufactured in Sweden. She will be full-rigged, the masts of iron, having been made in England, and armed with ten 12-centimeter guns on the 'tween deck, and two 15-centimeter on the upper deck. The cost of the vessel is £85,000.

The following, from the *Railway Register*, is given by the *Journal of Railway Appliances* as "A St. Louis Bull." "Many iron boilers now in use have a record for efficient and continuous service extending over periods of time varying from a quarter to a third of a century. Iron can afford to stand by such a record as this. Are there any steel boilers with records that will compare favorably with these iron boilers?" As a comment, the *Journal* adds: "Show us the building of the present day," says the Hibernian orator, "which has lasted as long as those of antiquity." We may add that a quarter of a century of antiquity may be found in a steel fire-box in a boat on a Westmoreland lake, and described in *The Engineer*, August 13th, 1880.

BOOK NOTICES.

Publications Received.

Bulletins of the United States Geological Survey. Nos. 7 to 14.

No. 7.—A Catalogue of Geological Maps ... tive to North and South America.

No. 8.—Report of work done in Washington Laboratory during fiscal year 1883-4.

No. 9.—On Secondary Enlargements of Mineral Fragments in certain rocks.

No. 10.—On the Cambrian Faunas of North America.

No. 11.—On the Quaternary and Recent Mollusca of the Great Basin.

No. 12.—A Crystallographic study of the Thinolite of Lake Lahonton.

No. 13.—Boundaries of the United States, and of the several States and Territories, with a historical sketch of the territorial changes.

No. 14.—On the Physical Characteristics of the Iron-carburets, more particularly on the galvanic thermo-electric and magnetic properties of wrought iron and steel.

Washington: Government Printing Office.

The Prospector's Hand-book. By J. W. Anderson, M. A. London: Crosby, Lockwood & Co.

This is designed to be an aid to the out-door seeker after useful minerals. It can hardly be more than a suggestion, however, to a learner of right instincts, to prompt him to look up better sources of knowledge. The book is so small that everything is presented in too brief a manner to be of use to a novice in mineralogy or geology.

As a guide to the learner, directing him to the proper studies in acquiring skill in prospecting it may not be amiss.

Statistics of Hydraulic Works and Hydrology of England, Canada, Egypt and India. By Lewis d' A. Jackson. London: W. Thacker & Co.

This work contains valuable information regarding completed works. A large portion of it is in the form of tabulated statistics.

Rivers, canals, sewage irrigation, storage of water, with cost of construction, cost of maintenance, and productive value are the chief topics upon which the text of the book is based.

The work must prove particularly serviceable to engineers who undertake hydraulic works in either of the four specified countries, and of some value in any country where such works are in operation.

The book is well printed, but is without maps or diagrams.

A Primer of Orthographic Projection. By Major G. T. Plunkett. London: Sampson Low & Company.

This is a book for beginners in mechanical or architectural drawing, and will suit the wants of learners without teachers.

The diagrams are interspersed throughout the text, and the exercises are graded with skill. The treatise is an easy guide to the more advanced problems of descriptive geometry.

Mechanical Integrators. Van Nostrand's Science Series, No. 83. By Professor Henry S. H. Shaw. New York: D. Van Nostrand.

We are by no means certain that the title of this unique treatise will convey to the general reader an adequate idea of the scope of the work. To have called it an essay on planimeters would have only partially explained the author's design, but would not have proven to a great extent misleading.

Professor Shaw has given complete analyses of a large number of mechanical measuring machines; classifying them, describing their construction, and expounding the principle of action.

As a record of inventions of a peculiar kind, the work is very interesting, and as affording illustrations of mechanical solutions of complex computations, it is very instructive.

A Report on the Terminal Facilities for handling Freight by the Railroads entering the port of New York, especially of those Railroads having direct Western connections. Written and prepared for the *Railroad Gazette* by Gratz Mordecai. New York: *Railroad Gazette*.

A preliminary analysis of railroad work and accounts, and an investigation of the general subject of terminal work as it is illustrated at New York, closing with a general summary and conclusions derived from the information given, which consists of the detailed plans of, and the methods and approximate cost of oper-

ating, the several yards and freight houses, and including a partial industrial map of New York.

Octavo pamphlet, 68 pages text and 6 large lates. In flexible cloth, $1.50.

MISCELLANEOUS.

THE proportion of organic matter present in the water supplied from the rivers to London during the month of October, though slightly in excess of that characterizing the supply of the past three months, was found to be very small, and exceptionally small in view of the year and of the swollen state of the river. The report of Mr. William Crookes, F. R. S., Dr. William Odling, and Dr. C. Meymott Tidy, states that the average proportion of organic carbon in the Thames-derived supply of the month was .128 part, and the maximum proportion in any one sample .145 part in 100,000 parts of the water, as against an average of .119 part, and a maximum of .146 part, for the preceding three months. In respect to state of aeration, and degree of freedom from color, and from any trace of turbidity, the quality of the water supplied by all the seven companies was unexceptionable.

ALLOYS of copper with cobalt are readily obtained by melting the two metals together under a flux of boric acid and wood charcoal, or by melting copper with an alloy of copper and cobalt, which is formed in the process of copper-smelting. The alloy used by M. Guillemin for this purpose had the composition Co, 48.28; Ni, 1.0; Cu, 50.26; Fe, 0.46=100. The alloys investigated contained from 1 to 6 per cent of cobalt. They have a red color, and a fine silky fracture, resembling that of pure copper. They have remarkable ductility, malleability and tenacity, and can be worked and rolled in the cold, but they cannot be tempered. They break under a tensile strain of from 25 to 36 kilos. per square millimeter, with an elongation of 28 to 15 per cent. An alloy containing 5 per cent. of cobalt, after forging and rolling, broke under a strain of 40 kilos. per square millimeter, with an elongation of 10 per cent. This particular alloy, the *Journal of the Chemical Society* says, is as malleable and as little liable to oxidation as copper, and is as ductile and tenacious as iron.

THE supply of potable water in the Roman Campagna is one of the most urgent necessities in the improvement of this vast district. In order to provide one of the forts recently constructed for the defence of Rome with water, a boring was made by the military authorities for this purpose. This fort is situated near the tomb of Cecilia Metilla, on the Appian Way, about 2½ miles beyond the city walls, and at 70.30 meters—230.58 ft.—above the level of the sea. The results (Proc. Inst. C. E.) are most interesting, and show the advantage that may be derived from boring, as water, both for irrigation and potable uses, may be obtained by this means, for at a depth of 42.12 meters—138.15 ft.—or 28.18 meters—92.33 ft.—above the level of the sea, the first water-bearing stratum was found in the volcanic deposits, whilst a second was reached at a depth of 83.30 meters—273.22 ft—or 13 meters—42.64 ft.—below the level of the sea in the quartertiary formation. The bore hole, which was 32 centimeters—12.6 in.—in diameter, was carried down to the depth of 90 meters—293.2 ft.—below the surface. Kind's percussion boring apparatus was used.

A NEW process for smoothing, polishing and fluting stone by machine power without the use of edge tools—the invention of Messrs. W. and T. Brindle, of Upholland, near Wigan—is now being developed by them in conjunction with Messrs. M. Powis, Bale & Co., of Appold Street, Finsbury. This process consists essentially in causing a revolving or reciprocating surface of iron to alternately bear against the surface of the stone to be worked, and then parted from it sufficiently to receive a layer of fresh sand and water between the rubbing surface and the rubbed. The rubbing surface is held down by a spring, but at intervals is raised from the rubbed surface by an eccentric cam. For fluting and similar operations a series of round bars of wrought iron are mounted in bearings and made to revolve; at the same time they are given a reciprocating movement. The block of stone to be fluted is placed on a trolly and run under the bars. Sand is sprinkled automatically over the bars or rollers as they revolve. For recessing, edge moulding, and similar purposes, rubbing disks are mounted on vertical spindles arranged to lift automatically for about half a revolution in every four. Several different types of machines are now in active operation. An advantage claimed for this process of working over hand labor with hammer and chisel, or machine work where cutters are forced into the stone, is that the surface of the stone is left perfectly smooth and "unstunned," and better capable of withstanding atmospheric influences. It is stated that fluted, recessed, and ornamental stone is now being sold by the inventors at 75 per cent. less than similar work produced by hand.

THE DEEPEST WELL.—Probably the deepest well in the world is one at Homewood, Pennsylvania, owned by Mr. George Westinghouse, jun. The average depth of the Homewood wells is about 1,850 ft. In the well now drilling everything found of the nature of gas or water at a depth of 2,000 ft. was cased off as unimportant, and the drill at present is said to be a little over 6,000 ft. below the surface, which would make it the deepest well in the world. A careful record is being kept, and portions of each formation encountered preserved. Since it would necessarily have to be a very prolific gas vein to justify such deep drilling, it is a difficult matter to conjecture the object that prompts such a work, unless it be purely to satisfy curiosity. There are in Washington County some wells drilled to a depth of 4,000 ft., and the only others, so far as known, approaching the depth reached by Mr. Westinghouse, is an artesian well in France, at which a depth of 5,000 ft. was reached.